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SOME FACTORS AFFECTING THE SURVIVAL OF ARTIFICIALLY FROZEN FRUIT BUDS OF PEACH[1]

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INTRODUCTION

Varieties of peach (*Prunus persica* (L.) Batsch) with fruit buds capable of withstanding temperatures 1° or 2° F. lower than other varieties frequently will bear a crop of fruit when the tenderer varieties bear none. The development of varieties that will produce fruit of good quality and have cold-resistant buds is one of the objectives of the peach-breeding work at the Plant Industry Station, Beltsville, Md. In order to develop varieties with hardy buds by breeding, it is necessary to choose parents known to carry factors for cold hardiness. A number of years may be required, however, to select cold-resistant parents and seedlings under prevailing weather conditions, since during many winters temperatures are not sufficiently low to provide test conditions for dormant buds and during many springs frosts do not occur at blossomtime to test the hardiness of the buds. Consequently, hardy varieties must be selected either after winters with sufficiently low temperatures to provide test conditions or by developing and using some artificial method of testing their hardiness.

To use an artificial method it is necessary to determine its feasibility for evaluating the cold hardiness of peach varieties and their progenies and the effects that certain factors may have upon fruit buds subjected to freezing. From investigations previously reported it is apparent that many factors are involved in any study of cold resistance. If an artificial-freezing technique is to be used, it is important to know what factors are of major importance and how they may affect the results.

As dormant fruit buds of peach are more susceptible than wood to low-temperature injury under most conditions, fruit buds were used in all of the present study, which was begun in the winter of 1939–40.

REVIEW OF LITERATURE

The cold hardiness of many different kinds of plants has been widely investigated. For an excellent recent critical review of the literature on hardiness the reader is referred to Levitt[2] and for an extensive bibliography to Harvey.[3] The present review will be confined largely to studies that have dealt with stone fruits, particularly peaches.

[1] Received for publication February 3, 1945.

[2] LEVITT, J. FROST KILLING AND HARDINESS OF PLANTS; A CRITICAL REVIEW. 211 pp. Minneapolis, Minn. [Processed.]

[3] HARVEY, R. B. AN ANNOTATED BIBLIOGRAPHY OF THE LOW TEMPERATURE RELATIONS OF PLANTS. 240 pp. Minneapolis, Minn. [Processed.]

Many of the investigations of hardiness have been concerned with environmental factors that influence freezing injury. The degree of cold resistance of plants depends upon maturity as well as upon environmental factors, and frequently the former can be influenced by cultural treatments. Emerson (*17*)[4] stressed the fact that resistance to cold in fruit trees was often due almost entirely to the habit of early maturity rather than to constitutional hardiness. Emery (*18*) pointed out that temperatures well above 0° F. in early winter often cause more injury than −30° or −40° later. Green and Ballou (*23*) reported that peach trees growing in rich, moist soil or under late cultivation were more severely injured because of immaturity than similar trees growing in sod or under grass mulch. Emerson (*16*) found essentially the same relation. Crane (*10*) showed that severe pruning or heavy application of fertilizer reduced the fruit-bud hardiness of both the tender Salwey and the hardy Greensboro varieties of peach. McMunn and Dorsey (*36*) stated that the vigor of peach trees had no effect on hardiness under the conditions of their experiment. Bradford and Cardinell (*4*) reported that lack of maturity is the greatest factor in inducing winter injury and that late cultivation and heavy fertilization proved to be unwise practices.

That hardiness varies with the season was pointed out by Goff (*22*), Winkler (*52*), Hildreth (*25*), Cullinan and Weinberger (*11*), and others. Cullinan and Weinberger (*11*) showed that there is a seasonal trend for hardiness of peach buds, the buds being hardier in midwinter than in late fall or early spring. Johnston (*31*), using an electrometric method to study the undercooling effect on peach buds, noted that the buds became progressively tenderer toward spring. Askenasy (*1*), from a study of sweet cherry, and Knowlton and Dorsey (*34*), from an examination of peach buds in West Virginia, showed that the fruit buds made continuous growth from fall until spring. Buds furthest advanced were the least hardy. Roberts (*43*) noted that in blossom buds of cherry the extent of killing varied directly with the degree of development. West and Edlefsen (*49*, *50*) determined the killing temperatures of various fruit buds and noted that the earlier the stage of development the hardier the buds.

Changes in weather conditions during the dormant season may affect hardiness. Whitten (*51*), Howard (*28*), Chandler (*6*), and Hooker (*27*) all pointed out that growth of peach buds during warm weather in winter makes them subject to freezing injury. Davis (*12*) showed that sour cherry buds that withstood −30° F. during January were killed by much higher temperatures in late February and early March. Gardner (*21*), in a study of sour cherry buds from different strains, showed that there were three types of low-temperature killing of the buds: killing of dormant buds, delayed winter killing, and killing of flower buds by spring frost. He found no correlation in susceptibility among the three and no close correlation between the degree of development that had been attained and susceptibility to injury.

Numerous investigations have been conducted to determine the relation between hardiness and physiological conditions of the plants. The length of the rest period in plum varieties was emphasized by Strausbaugh (*47*). Blake and Connors (*3*) reported that Elberta and

[4] Italic numbers in parentheses refer to Literature Cited, p. 236.

similar varieties begin growth the first warm days in winter and later may be severely injured, whereas Carman and Greensboro respond less quickly and are not damaged so severely by low temperatures. Knowlton and Dorsey (*34*) observed that the rest period ended earlier in a tender peach variety than in two hardy ones. Dorsey and Strausbaugh (*15*) stated that killing of the flower buds of plum occurred near midwinter each year in Minnesota at a time corresponding closely to the break in the rest period. Dorsey and Bushnell (*14*) stated that the most reliable indexes of hardiness in fruit trees are early maturity and a long rest period. Evidence was presented, however, by Howard (*29*), Johnston (*32*), Hodgson (*26*), and Knowlton and Dorsey (*34*) that the rest period in peaches is ended by early January and would not retard bud growth during late winter.

A factor of major importance in determining the injury resulting from a certain temperature is the rate of temperature fall, as has been shown by a number of investigators working with many different crops. Müller-Thurgau (*40*), while working on the undercooling factor for living and dead tissues, was one of the first to note this effect. Chandler (*7*), working with peach buds, reported that 97 to 100 percent of the buds were killed when cooled rapidly to −17° C., but when cooled slowly to −19.5° only 15 to 18 percent were killed. Meader, Davidson, and Blake (*38*), in developing a method of artificially freezing fruit buds of peach, noted that a slow rate of freezing gave much less injury than a relatively rapid drop in temperature. Similar results for apple shoots and roots were shown by Beach and Allen (*2*), Mix (*39*), Carrick (*5*), Potter (*41*), Hildreth (*25*), and Field (*19*). Hardening of plant tissue increases with lower temperatures, as shown by Knowlton (*33*), Field (*20*), Meader and Blake (*37*), and others.

The length of time that plant tissues are frozen may affect the degree of injury. Chandler (*8*) was unable to decide definitely whether the length of time at the minimum temperature was the causal agent, but Potter (*41*), Hildreth (*25*), and Field (*19*, *20*) all seem to agree that the longer the period at the low temperatures the greater the injury.

There seems to be rather general agreement that rapid thawing of the tissue does not produce a greater degree of injury than slow thawing. This has been pointed out by Chandler (*7*), Winkler (*52*), Carrick (*5*), Potter (*41*), Hildreth (*25*), Levitt,[5] and others. Hildreth (*25*) noted that when apple twigs were thawed extremely quickly by thrusting them into hot water or mercury the degree of injury seemed to be worse, but the type of injury was not typical for tissue naturally injured by cold.

Results of studies on the effect of mineral nutrition on hardiness vary. Couturier (*9*) found crops fertilized with potash more resistant to low temperatures than those not so treated. Chandler (*7*) got no increased hardiness of peach fruit buds by application of potassium fertilizer to the soil. Harvey (*24*) observed that plants watered with solutions which produce rapid growth were more readily injured than those watered with solutions that retard growth. The former all contained nitrogen and the latter only nonnitrogen salts. Knowlton and Dorsey (*34*) noted a higher percentage of live buds on peach trees which had received applications of nitrate than on those which had

[5] See footnote 2, p. 209.

not. Chandler (*8*) observed that injured trees treated with sodium nitrate recovered much faster than untreated ones, so that ultimate injury appeared to be less on the trees supplied with sodium nitrate.

Water content seems to affect the hardiness of plants. Shutt (*44*) reported that twigs of hardy varieties of apples were low in moisture. Chandler (*7*) sawed off limbs of peach trees and suspended them among the other branches. When in a wilted or semiwilted condition, the buds of these limbs proved more resistant than the normal turgid ones. Johnston (*30, 31, 32*) observed a minimum moisture content in peach buds during winter. In three varieties moisture content during winter varied inversely with hardiness. Strausbaugh (*47*) found that the moisture content of a semihardy plum fluctuated during the dormant period, dropping at low and rising at high temperatures. In the case of a hardy variety it remained fairly constant, irrespective of environmental changes. Potter (*41*) dried apple roots until their moisture content was 5 percent below that of the controls, which contained 55 percent water. When frozen at −8° C., the two groups had 12.8 percent and 27.5 percent injury, respectively. Hildreth (*25*) tested two apple varieties for moisture content; that of the hardy one remained practically constant throughout the winter, but that of the tender one fluctuated. Crane (*10*) found a high inverse relation between total bud moisture and hardiness of fruit buds of two peach varieties: the more tender buds of Salwey had a higher moisture content than the hardier ones of Greensboro. Rivera and Corneli (*42*) observed that low-temperature injury to olives, grapes, and peaches was favored by moist soil or atmosphere. Stark (*46*) found no correlation between moisture content and hardiness of apple varieties, though a marked decrease in moisture occurred from summer to winter. Stuart (*48*) showed that hardy apple roots contain slightly less moisture than tender ones. Field (*20*) found that the buds of a crab apple and of a tenderer apple variety contained the same amount of moisture, but in this case the hardy variety had only slight hardiness.

MATERIALS AND GENERAL METHODS

Studies were begun in the winter of 1939–40 and carried through the 1941–42 season. Practically none of the peach fruit buds were killed by low temperature in the field during the three seasons. Nor were there unseasonably warm periods in the winter that might have started tree growth. The trees used were growing in the variety orchard at the Plant Industry Station, Beltsville, Md. Vigorous 5- to 8-year-old trees that had produced crops during the preceding 2 years were used in all cases. Usually four trees of each variety planted in squares in the orchard were available as a source of material for freezing, but in some cases there were only two trees of a variety.

Wherever variety comparisons were made, individual-tree samples were gathered; 1-year wood of moderate size, 12 to 18 inches long, and plentifully supplied with fruit buds was selected. In the winter of 1939–40, entire twigs of this selected length were frozen and all the buds were examined. In the last two seasons, because of the small size of the freezing chamber available, it was necessary to compromise on the length of the twigs; consequently, only the basal

10½ inches of each twig was frozen (fig. 1), but the samples were rigidly selected within 12- to 14-inch lengths. It was believed that cutting 2 or 3 inches off the tips would not materially alter any comparisons between samples, since preliminary trials had shown no significant effect on bud survival when this was done.

Two freezing chambers of different types were used. In 1939–40 a large freezing room, 8 by 12 feet, was available for the investigation. Because of the size of the room and the type of freezing apparatus it was not possible to raise the temperature in the room between freezing runs and then gradually lower it to the minimum. Instead it was necessary to have the chamber at the desired minimum and place the samples immediately at the selected low temperature. For the 1940–42 studies a small compressor freezing unit was used. The air chamber in which the samples were frozen was 11 by 33 by 6 inches and was equipped with a small fan, which circulated the air and prevented its stratification. Mounted in front of the fan was a 200-watt cartridge heater used to reduce the rate of temperature fall. A self-recording thermograph was used, and in addition eight thermocouples were placed in the chamber to check on any variation in temperature that might occur while the box was cooling down.

A minimum thermometer was placed on the floor of the chamber to serve as a check on the thermograph. The air temperature in the freezing chamber fluctuated 2° F. between high and low points

FIGURE 1.—Elberta shoots, showing the length and type of twigs used for freezing studies.

while at the low temperature, and the value used in the discussion is the lowest temperature recorded for each trial. Some preliminary freezing runs showed there was no stratification of the cold air in the chamber.

Unbranched terminal or lateral shoots near the outer periphery of the tree were used as samples in all cases. These were usually cut from the trees in the morning, brought immediately to the laboratory, and put in the freezing chamber at once. After the shoots had been frozen for the desired length of time, the chamber was opened and the samples were removed immediately and left at room temperature to thaw.

Two methods of determining injury to the fruit buds were used. In the early trials exosmosis of salts as determined by electrical conductance was tried as a means of detecting injury to the buds. Each sample of fruit buds was divided into three lots of 0.5 gm. each so that triplicate readings could be made. The twigs were frozen; after thawing, the fruit buds were plucked off and put in test tubes and 25 cc. of distilled water was added. The samples were left overnight at room temperature, then they were put in a constant-temperature bath, and readings were made as soon as temperature equilibrium was established.

The other method used for determining injury was to slice the fruit buds transversely through the floral axis and examine them with the naked eye for brown tissue; if injury was doubtful the buds were examined with a binocular also. Buds were classed as dead or alive, depending on whether there was presence or absence, respectively, of brown tissue in the floral organs. Care was taken to cut through the ovary, since its tissue seemed to be most sensitive to freezing injury. In order to permit sufficient browning of the injured tissue, examinations were not made until about 24 hours after the buds were removed from the freezing chamber.

Chi square (χ^2) was used in the statistical treatment of the data because of their discrete nature (*45*). When comparisons are made between more than two varieties or more than two treatments, the results are indicated in a manner similar to that used for partial correlation. Thus in table 8, for example, 1, 3** means that treatment 1 was compared with treatment 3 and found to be highly significantly different.[6]

USE OF ELECTRICAL CONDUCTANCE AS A MEANS OF DETERMINING INJURY

Electrical conductance was tried as a means of determining relative injury to frozen peach buds, since it has been used to determine the degree of injury to frozen tissue of apples (*48*) and of alfalfa (*13*), the more severely injured tissues of which released a greater amount of electrolytes. Preliminary freezing runs were made with three varieties known to differ in relative hardiness. Different temperatures were used in order to locate a temperature that might show varietal differences in conductance. The buds were frozen between January 10 and 25, 1940; the results are given in table 1. The average of

[6] Acknowledgment is made to M. F. Babb, Division of Fruit and Vegetable Crops and Diseases, Cheyenne Horticultural Field Station, for this suggestion.

the mhos [7] for all three varieties indicates that a difference in conductance was obtained for the different temperatures used but not necessarily for the varieties. Samples frozen at 0° and +5° F. were about the same. Those frozen at +10°, however, were no different from the unfrozen samples. When the unfrozen samples were boiled to obtain the maximum degree of conductance, no difference in release of electrolytes was found among varieties. The averages of material frozen at +7.5° suggested varietal differences in conductance, but values for triplicate readings varied greatly. Frequently there was a greater difference among readings within a sample than among varieties. In these data there was no correlation between number of buds in a sample and the amount of conductance.

Because of the variability obtained in triplicate readings of a sample, different techniques were tried in an effort to eliminate some of the variation. Accordingly, bud samples were selected and compared from two places on the twigs—the basal and the apical half. The data (table 2) showed again that there may be a difference in conductance, depending on the freezing temperatures used; in general, buds from the tip showed the most injury, except those of Cumberland frozen at +7.5° F. Variation among readings was still very large.

TABLE 1.—*Conductance of buds of 3 varieties of peach frozen for 17 hours at different temperatures*

[Buds on twigs frozen between Jan. 10 and 25, 1940; buds boiled for 30 minutes; conductance determined for 0.5 gm. of buds in 25 cc. of water]

Variety and treatment	Buds in each sample	Conductance of each sample	Average conductance
Greensboro:	*Number*	*Mhos*	*Mhos*
Freezing at 0° F		4,676; 4,696; 4,716	4,696
Freezing at +5° F	30; 29; 31	4,948; 6,052; 3,952	4,984
Freezing at +7.5° F	30; 30; 28	7,428; 6,608; 7,940	7,325
Freezing at +10° F	32; 31; 30	10,600; 10,600; 9,512	10,237
None	32; 32; 32	8,988; 10,284; 9,556	9,609
Boiling	32; 32; 32	1,594; 1,617; 1,657	1,623
Cumberland:			
Freezing at 0° F			
Freezing at +5° F	30; 30; 31	4,316; 4,212; 4,064	4,197
Freezing at +7.5° F	27; 30; 26	5,344; 5,828; 6,668	5,947
Freezing at +10° F	31; 28; 29	8,460; 8,780; 9,604	8,948
None	24; 25; 24	9,468; 9,028; 8,384	8,960
Boiling	24; 25; 24	1,763; 1,772; 1,586	1,707
Hiley:			
Freezing at 0° F		4,016; 4,332; 4,300	4,216
Freezing at +5° F	28; 31; 31	3,299; 3,575; 3,766	3,547
Freezing at +7.5° F	34; 29; 32	5,756; 7,468; 6,752	6,659
Freezing at +10° F	33; 34; 31	9,376; 8,272; 7,396	8,348
None	31; 33; 26	8,460; 9,512; 9,744	9,239
Boiling	31; 33; 26	1,509; 1,594; 1,517	1,540
All varieties:			
Freezing at 0° F			[1] 4,456
Freezing at +5° F			4,243
Freezing at +7.5° F			6,644
Freezing at +10° F			9,178
None			9,269
Boiling			1,623

[1] 2 varieties only.

[7] Mho is the unit of conductance, which is the reciprocal of ohm; for convenience the numerical value is the same as the value for ohms rather than the quotient of $\frac{1}{\text{ohms}}$.

TABLE 2.—*Conductance of buds from apical and basal halves of twigs of 3 varieties of peach frozen for 17 hours at 2 temperatures*

[Buds on twigs frozen Jan. 14 and 15, 1940; conductance determined for 0.5 gm. of buds in 25 cc. of water]

Variety and treatment	Half of twig sampled	Buds in each sample	Conductance of each sample	Average conductance
		Number	*Mhos*	*Mhos*
Greensboro:				
Freezing at +7.5° F.	Apical	30; 30; 30	6,308; 6,928; 5,900	6,379
	Basal	31; 30; 28	7,428; 6,608; 7,940	7,325
Freezing at +10° F.	Apical	28; 30; 30	8,084; 9,840; 8,900	8,941
	Basal	32; 31; 30	10,600; 10,600; 9,512	10,237
Cumberland:				
Freezing at +7.5° F.	Apical	26; 27; 25	6,284; 7,172; 6,668	6,708
	Basal	27; 30; 26	5,344; 5,828; 6,668	5,947
Freezing at +10° F.	Apical	29; 27; 27	7,428; 7,800; 6,988	7,405
	Basal	31; 28; 29	8,460; 8,780; 9,604	8,948
Hiley:				
Freezing at +7.5° F.	Apical	25; 26; 26	5,196; 4,868; 5,900	5,321
	Basal	34; 29; 32	5,756; 7,468; 6,752	6,659
Freezing at +10° F.	Apical	27; 27; 26	6,388; 5,304; 5,684	5,792
	Basal	33; 34; 31	9,376; 8,272; 7,396	8,348

In one of the attempts to reduce variation between samples a comparison was made between entire fruit buds and those sliced longitudinally. The results are summarized in table 3. There was a much greater release of electrolytes from the sliced buds, as reflected in the lower reading in mhos of sliced than of entire buds. Variation was less in the samples of sliced buds than in entire buds, and there was some indication of varietal differences with respect to electrolyte release. Slicing the buds longitudinally is laborious, however, and direct observation of injury to transversely cut buds is more feasible.

TABLE 3.—*Conductance of longitudinally sliced and entire buds of 3 varieties of peach frozen for 17 hours at +7.5° F.*

[Buds on twigs frozen on Jan. 14 and 15, 1940; conductance determined on 0.5 gm. of buds in 25 cc. of water]

Variety and condition of buds	Buds in each sample	Conductance of each sample	Average conductance
	Number	*Mhos*	*Mhos*
Greensboro:			
Sliced	31; 30; 32	3,505; 3,273; 3,563	3,447
Entire	30; 30; 28	7,428; 6,608; 7,940	7,325
Cumberland:			
Sliced	29; 27; 28	2,514; 3,116; 2,993	2,874
Entire	27; 30; 26	5,344; 5,828; 6,668	5,947
Hiley:			
Sliced	28; 32; 32	2,849; 2,992; 2,980	2,940
Entire	34; 29; 32	5,756; 7,468; 6,752	6,659

A final means of evaluating the conductance method as a measure of injury of peach fruit buds consisted of a comparison between mho readings and percentage of buds alive as determined by visual examination. The size of the conductance sample was doubled (increased from 0.5 to 1 gm. of buds). Buds for both sets of values were taken from the same bundle of twigs. The conductance readings were made on unsliced buds. The results are shown in table 4. The values show that in many cases there was no relation between the amount of conductance and the percentage of buds alive. Because of this lack of agreement, the large variation in conductance readings, and the

fact that the method was not as rapid as anticipated, the conductivity method was abandoned as a means of determining injury of dormant fruit buds of peaches.

TABLE 4.—*Relation of the conductance of buds of 7 varieties of peach to the percentage of buds surviving*

[Buds on twigs frozen for 17 hours at +9° F., Feb. 15, 1940; conductance determined on 1 gm. of bud in 25 cc. of water, with 3 samples per tree; 200 buds per tree cut and examined]

Variety and tree	Average buds in sample	Average conductance		Buds surviving	Variety and tree	Average buds in sample	Average conductance		Buds surviving
		After boiling	Before boiling				After boiling	Before boiling	
Mikado:	*Number*	*Mhos*	*Mhos*	*Percent*	Golden Jubilee:	*Number*	*Mhos*	*Mhos*	*Percent*
1	59	556	5,334	82.5	1	59	596	5,181	72.5
2	58	599	5,326	88.0	2	57	549	5,194	70.0
3	62	615	5,585	88.5	3	56	550	5,022	67.5
4	59	576	5,337	79.0	4	60	602	6,633	64.0
Greensboro:					Admiral Dewey:				
1	60	716	6,188	77.5	1	80	545	3,383	63.5
2	62	667	6,790	76.5	2	62	533	3,641	67.5
3	58	653	6,457	85.0	Hiley:				
4	55	625	6,468	76.5	1	58	568	5,942	56.5
Veteran:					2	60	593	7,040	60.5
1	62	561	5,269	63.0	3	56	556	6,418	49.0
2	63	556	5,401	75.5	Lemon Free:				
3	62	544	4,591	72.0	1	56	538	5,020	52.0
4	64	592	4,990	64.0	2	64	573	4,698	44.5
					3	64	520	3,914	41.5

DETERMINATION OF FREEZING INJURY BY VISUAL EXAMINATION

SIZE OF SAMPLE

Since buds on the same twig of a variety vary in resistance to cold injury, it was necessary to find out first what size of sample would give a reliable comparison between varieties. Five 7-year-old Elberta trees, uniform in size and vigor, were selected for source of buds, and sufficient twigs were frozen to furnish over 200 buds from each tree. These were collected on February 20, 1940, and frozen at +8° F. for 15 hours. The number of live buds in lots of 100, 150, and 200 were recorded; the results are shown in table 5. It can be seen that there was considerable variation between trees within each series of 100-, 150-, and 200-bud samples, although the χ^2 test showed the population in each series to be homogeneous. There was no significant difference between the different-sized samples. Since the coefficient of variability was somewhat smaller for the 150- and 200-bud samples than for the 100-bud sample, it was decided to use not less than 150 buds in each freezing test. In most of the work samples of 200 buds from each tree were examined and the data were reported on an individual-tree basis and not on a composite sample of bubs from a number of trees of a variety.

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TABLE 5.—*Comparison of percentages of fruit buds surviving after freezing for 15 hours at +8° F. in samples of different sizes from 5 Elberta peach trees. Feb. 20, 1940*

Tree	Buds surviving in sample of indicated size			χ^2
	100 buds	150 buds	200 buds	
	Percent	*Percent*	*Percent*	
1	47	43	46	0.39†
2	36	36	35	.05†
3	50	43	43	1.48†
4	46	42	45	.32†
5	40	36	38	.29†
Average	43.8	40	41.4	
Standard deviation	5.7	3.6	4.7	
Coefficient of variation	13	9.2	11.3	
χ^2	5.2	2.2	4.8	
P	20	60	30	

†Not significant.

VARIABILITY WITHIN VARIETIES

Elberta and Belle were the only two varieties of which sufficient trees were available to permit a study of tree variation. All these trees had been grown under the same cultural conditions. Individuals were picked at random, irrespective of their vigor or general appearance except that no definitely weak trees were sampled. Samples of these varieties were collected at three different times during February and March 1941 and frozen in the chamber for 13.5 hours at the minimum temperatures given in table 6. As indicated by bud survival, there is considerable variation among trees within a variety. These data emphasize the fact that a varietal evaluation should be based on more than one tree. It should be pointed out that the more severely the buds are injured the greater is the percentage difference in fruit-bud survival between trees, and that the differences in bud hardiness between varieties become accentuated as the bud injury increases.

TABLE 6.—*Survival of fruit buds of different trees of Elberta and Belle varieties of peach, 1941*

[Rate of temperature fall 6° F. per hour; kept at minimum for 13.5 hours; 200 buds per tree; χ^2 tests indicated that the trees within varieties were highly significantly different in all tests]

Treatment and variety	Buds surviving on tree										
	1	2	3	4	5	6	7	8	9	10	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Freezing at −3° F. on Feb. 20:											
Elberta	50.0	53.0	53.5	55.0	55.5	57.5	61.5	64.0	64.5	69.5	58.4
Belle	56.5	60.5	62.0	62.0	62.5	63.5	65.0	69.5	76.0	79.5	65.7
Freezing at −1° F. on Mar. 7:											
Elberta	22.5	24.5	25.5	27.5	29.5	32.5	36.0	36.0	36.5	.....	30.1
Belle	30.5	31.5	32.0	32.5	35.0	35.0	41.5	43.5	47.0	49.5	37.8
Freezing at −1° F. on Mar. 14:											
Elberta	13.0	15.0	18.0	19.5	22.5	25.5	28.5	29.0	29.0	30.0	23.0
Belle	34.5	39.5	41.0	43.0	43.5	44.0	49.0	51.0	52.0	53.0	45.1

EFFECT OF VARIOUS FACTORS ON BUD SURVIVAL

Size of Shoots

Two different types of shoots, growing either terminally or laterally on main branches, were used in studying the effect of size of shoot. The large shoots were 16 to 20 inches long and ¼ to 5/16 inch in diameter, whereas the medium ones were 12 to 15 inches long and 3/16 to ¼ inch in diameter at the butt. Table 7 shows greater survival of buds for all varieties on the larger wood. Table 8 shows the relatively poor survival on very short, thin shoots of the Elberta variety as compared with that on normal terminals and laterals.

To investigate further the effect of size of shoot on survival of buds when frozen artificially, slender shoots from potassium-deficient Elberta trees (shown by leaf analysis the previous summer) were compared with medium-sized shoots from nondeficient potassium trees. The shoots were frozen on February 24, 1941, at −4° F. for 13.5 hours, with a 5.5° per hour temperature fall to the minimum. Bud survival for 5 potassium-deficient trees averaged 17.2 percent and for 5 nondeficient trees 26.7; 200 buds were examined from each tree. Chi square showed the difference to be highly significant. Terminal growth on the potassium-deficient trees was slenderer than on normal trees. In the samples collected for freezing, the terminal lengths of shoots from potassium-deficient and normal trees were the same, but the potassium-deficient shoots were ⅛ to 1/16 inch smaller in diameter at the butts. The greater injury to buds on potassium-deficient shoots raises a question whether lack of potassium made the buds more susceptible to injury, but the effect of the potassium cation on cold resistance is not known. It is possible that the lack of potassium may have had a secondary effect on bud hardiness by causing weaker growth, as indicated by the slender twigs.

TABLE 7.—*Survival of fruit buds of 3 varieties of peach from shoots of different sizes when frozen at −2° F. for 16.5 hours, Feb. 10, 1941*

[Rate of temperature fall 8° F. per hour; all shoots of a single variety from the same tree]

Variety	Bud survival on shoots of indicated size				Significance of comparison as indicated by χ^2 test
	3/16 to ¼ inch at butt, 12 to 15 inches long		¼ to 5/16 inch at butt, 16 to 20 inches long		
	Examined	Surviving	Examined	Surviving	
	Number	*Percent*	*Number*	*Percent*	
Elberta	400	38.0	400	45.5	4.64*
Belle	600	35.0	200	47.0	9.16**
Greensboro	400	51.5	200	62.5	6.47*

*Exceeds 5-percent point. **Exceeds 1-percent point.

TABLE 8.—*Survival of fruit buds of Elberta peach from average terminals and laterals and from short growth when frozen at −6° F. for 13.5 hours, Jan. 22, 1942*

[Rate of temperature fall 7° F. per hour]

Tree	Bud survival on indicated shoot						Significance of comparison as indicated by χ^2 test [3]
	1. Terminal [1]		2. Lateral [1]		3. Short growth [2]		
	Examined	Surviving	Examined	Surviving	Examined	Surviving	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	
20–10	200	36.0	175	48.6	200	17.0	1, 2*; 1, 3**
20–9	200	51.0	179	47.5	200	12.5	1, 2†; 2, 3**
20–8	200	29.0	200	30.5	200	15.0	1, 2†; 2, 3**

[1] Shoots of the same size and unbranched.
[2] Twigs short (1 to 4 inches long) and thin in diameter.
[3] "1, 2*," for example, indicates that the difference in percentage of survival is statistically significant between treatment 1 (terminal) and treatment 2 (lateral) for tree 20–10.
†Not significantly different.
*Exceeds 5-percent point.
**Exceeds 1-percent point.

RATE OF FREEZING

Two methods were used to compare different rates of freezing. By one method two rates of temperature fall were compared in a single run by establishing a differential condition in the freezing chamber. This was done by placing a can 14 inches deep by 8 inches in diameter containing a 70-percent alcohol solution in the air chamber of the freezer. Shoots were placed in stoppered 12-inch test tubes, which were put in the can and plunged to their rims in the solution. The solution, referred to as the bath, was kept agitated by an electric-motor stirring apparatus. It was possible, therefore, to freeze samples at two different rates; as the minimum temperature was approached, those in test tubes in the bath were frozen more slowly

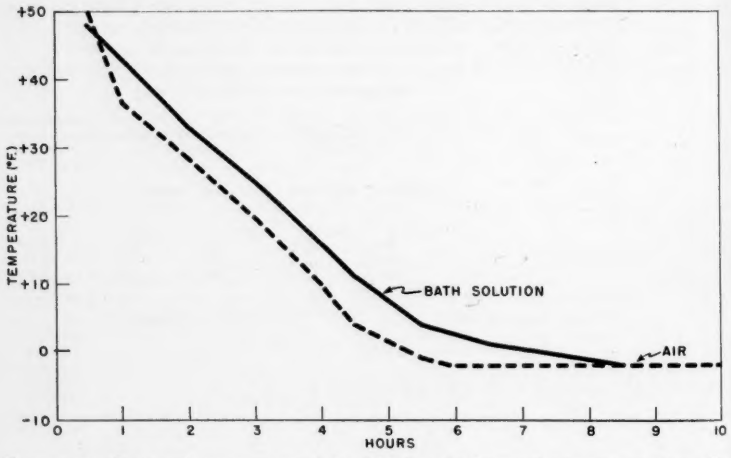

FIGURE 2.—Rate of temperature fall of bath solution and air surrounding the bath in the freezing chamber.

than those directly exposed to the air temperature of the freezing chamber (fig. 2).

Table 9 shows the difference in degree of injury sustained by fruit buds of three varieties when frozen simultaneously in the bath and in the air chamber. The experiment was conducted on two different dates with two different temperatures and with bundles of the same size. Injury was considerably less for buds frozen at the slower rate in the bath. It should be noted that there was a more clear-cut difference between samples of Belle and Elberta when frozen at −3° F. on January 31 than when frozen at −2° on February 10, probably because the −3° temperature caused more injury and thereby became more critical for fruit-bud survival.

TABLE 9.—*Effect of rate of temperature fall on survival of fruit buds of 3 varieties of peach frozen in a bath to retard rate of temperature fall and in air, 1941*

[All samples for one date frozen at same time and kept at minimum temperature for 16 hours; 200 buds per sample]

Date	Temperature conditions		Treatment of shoots	Buds surviving			Significance of comparison as indicated by χ^2 test		
	Minimum temperature	Rate of fall per hour		Elberta	Belle	Greensboro	Elberta	Belle	Greensboro
	°F.	°F.		*Percent*	*Percent*	*Percent*			
Jan. 31	−3	5.4	1. In test tubes, in bath	36.0	47.5	55.0			
		8	2. In test tubes, no bath	12.5	20.5		1, 2**	1, 2**	
		8	3. In bundles, no test tubes	14.0	26.0	30.5	2, 3†	2, 3†	1, 3**
Feb. 10	−2	5.5	1. In test tubes, in bath	56.5	59.5	69.5			
		8	2. In test tubes, no bath	37.0	33.0	52.0	1, 2**	1, 2**	1, 2**
		8	3. In bundles, no test tubes	39.0	36.0	51.0	2, 3†	2, 3†	2, 3†

†Not significantly different. **Exceeds 1-percent point.

With the second method the rate of freezing was varied by placing a heating element in the chamber to regulate the rate of temperature drop. With this method it was necessary to make separate runs with a 1-day period between them to compare the effect of rate of temperature fall on injury to the buds.

Bud injury was greatly reduced when a heating element was used in the freezing chamber for the February 24 trial to slow down the rate of temperature fall as compared with the February 22 trial (table 10). The difference in hardiness of Belle and Elberta could not be detected when the temperature was lowered rapidly, but there was a difference when they were frozen with a slow rate of cooling under the conditions shown for February 24. With a slow rate of freezing more buds of both hardy and tender varieties appear capable of surviving at a lower temperature than would be possible with a fast rate of freezing. Buds frozen on February 7 by placing them immediately at the minimum temperature of −2° F. and holding for only 2 hours were severely damaged.

TABLE 10.—*Effect of rate of temperature fall on survival of fruit buds of 2 varieties of peach, 1941*

[200 buds per sample]

Date	Temperature conditions: Minimum temperature	Temperature conditions: Rate of fall per hour	Temperature conditions: Held at minimum temperature	Variety	Buds surviving on indicated tree: 1	2	3	4	Average	Significance of comparison as indicated by χ^2 test
	°F.	°F.	*Hours*		*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
Feb. 7	−2	(1)	2	1. Elberta	2.0	------	------	------	2.0	------
				2. Belle	1.0	------	------	------	1.0	1, 2†
22	−4	10	13.5	3. Elberta	1.0	1.0	4.0	4.0	2.5	------
				4. Belle	5.0	4.0	1.0	2.5	3.1	3, 4†
24	−4	[2] 5.5	13.5	5. Elberta	28.5	27.0	34.0	23.5	28.3	3, 5**; 3, 6**
				6. Belle	38.5	33.0	49.0	34.5	38.8	4, 6**; 5, 6**

[1] Put at minimum temperature.
[2] Rate of temperature fall retarded by the heater.
†Not significantly different.
**Exceeds 1-percent point.

MINIMUM TEMPERATURE AND ITS DURATION

Tables 11 and 12 show the results of leaving the samples at the minimum temperature for short and long periods for each trial. In all cases considerably more injury was caused by leaving the samples at the minimum temperature for a relatively long period, although a large percentage of the buds were killed during the first few hours at the minimum. Thus, both the minimum temperature reached and its duration are apparently important in determining bud survival.

TABLE 11.—*Effect of duration of the freezing temperature on the survival of fruit buds of 3 varieties of peach, 1941*

[200 buds per sample]

Date and variety	Temperature conditions: Minimum temperature	Temperature conditions: Rate of fall per hour	Buds surviving after indicated period at minimum temperature: 1 hour	13.5 hours	16.5 hours	Significance of comparison as indicated by χ^2 test
Feb. 6:	° F.	° F.	*Percent*	*Percent*	*Percent*	
Elberta	−2	7.5	65.5	----------	33.5	**
Belle			68.5	----------	35.5	**
Greensboro			75.0	----------	49.5	**
Elberta	−2	8	69.0	----------	37.5	**
Belle			71.5	----------	30.5	**
Feb. 17:						
Elberta	−3	5.7	50.0	13.5	----------	**
Belle			61.5	32.0	----------	**

**Exceeds 1-percent point.

TABLE 12.—*Effect of duration of the freezing temperature on the survival of fruit buds of Elberta peach, 1942*

[Buds for Jan. 20, a composite sample from 16 trees, with 2 shoots from each tree in each group; buds for Jan. 22, a composite sample from 20 trees, with 2 shoots from each tree in each group]

Date	Temperature conditions		Held at minimum temperature	Buds examined	Buds surviving	Significance of comparison as indicated by χ^2 test
	Minimum temperature	Rate of fall per hour				
	°F.	°F.	*Hours*	*Number*	*Percent*	
Jan. 20	−7	7.5	1. (1)	187	38.5	
			2. 0.5	359	9.5	1, 2**
			3. 1.5	347	4.0	2, 3**
			4. 4	385	1.3	3, 4*
			5. 13	366	1.0	3, 5*
22	−6	7	1. (1)	485	58.3	
			2. 0.5	445	45.1	1, 2**
			3. 1.5	465	35.0	2, 3**
			4. 4	499	39.7	3, 4†
			5. 13	484	25.2	4, 5**

[1] Shoots removed at once when minimum was reached.
† Not statistically significant.
*Exceeds 5-percent point.
**Exceeds 1-percent point.

A comparison of live buds on shoots frozen at −3° and −4° F. in 1941 shows that a large amount of injury resulted from lowering the temperature 1° (table 13). The average survival at −3° was 58 percent on Elberta and 65 percent on Belle, whereas at −4° all but 28 and 39 percent, respectively, of the buds were killed. During the 4-day interval between freezing determinations the weather remained rather constant. Under field conditions Belle is considered medium hardy and Elberta relatively tender. When the hardiest varieties have been compared with the tenderest ones at critically low artificial-freezing temperatures, both classes have been greatly changed by a 1° change in temperature.

TABLE 13.—*Effect of the minimum temperature on survival of fruit buds of 2 varieties of peach when frozen for 13.5 hours at the minimum, 1941*

[200 buds per sample]

Date	Temperature conditions		Variety	Buds surviving from indicated tree					Significance of comparison as indicated by χ^2 test
	Minimum temperature	Rate of fall per hour		1	2	3	4	Average	
	°F.	°F.		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Feb. 20	−3	6	1. Elberta	50.0	53.5	64.0	64.5	58.0	
			2. Belle	62.0	63.5	65.0	69.5	65.0	
24	−4	6	3. Elberta	23.5	27.0	28.5	34.0	28.3	1, 3**
			4. Belle	33.0	34.5	38.5	49.0	38.8	2, 4**

**Exceeds 1-percent point.

The seasonal fluctuation in fruit-bud hardiness as affected by the minimum temperature of the freezing chamber is shown in figure 3. During the 1940–41 and 1941–42 seasons the winter temperatures were uniform with no unseasonably warm days until late in March. There was apparently no decrease in hardiness of Elberta buds at the end of the rest period, and it was not until the trees had been exposed to some warm temperatures that a change in hardiness could be detected. Elberta buds frozen February 24, 1941 (see table 20), had 28 percent alive as compared with only 8 percent for those frozen at

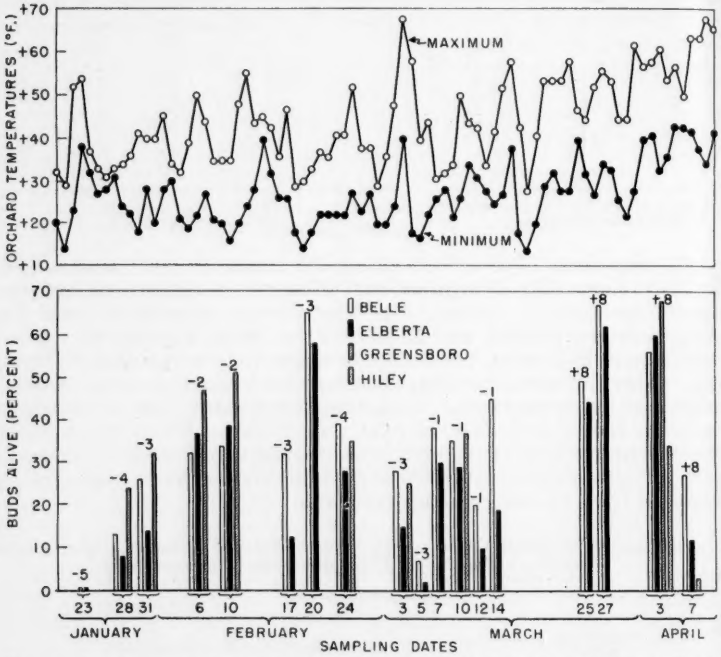

FIGURE 3.—Seasonal fluctuation in survival of fruit buds of Belle, Elberta, Greensboro, and Hiley varieties of peach as affected by fluctuation in orchard temperature when buds are frozen artificially at the minimum temperatures (° F.) shown at the top of the bars, on indicated dates, 1941.

the same temperature minimum and at the same rate of temperature fall on February 26. The February 26 freezing trial was made the day after the temperature had reached a maximum of +52° F. for 4 hours. It cannot be said positively that this maximum field temperature made all the difference in the bud survival in the two trials, but from February 26 until the tests were ended in April the buds became progressively more tender as the days became warmer. By March 25 Elberta buds were in the advanced gray stage (fig. 1), with 44-percent survival when they were frozen at +8°. On April 7 the buds were showing pink and 12 percent survived at +8°. In contrast to the change in hardiness of Elberta fruit buds that of Hiley is of interest.

About March 1 Hiley fruit buds were as hardy as or even hardier than those of Elberta, but as the buds became tender in early April Hiley buds became relatively much more tender than those of Elberta. Other varieties, however, such as Greensboro and Veteran, seemed to become tender more slowly than Elberta.

Differentiation between varieties is not apt to be evident if the minimum temperature used for the freezing determination is not low enough to kill a large proportion of the buds of tender varieties. Thus, in table 14 the difference between the Elberta and Belle varieties is not nearly so pronounced for the March 25 and 27 and April 3 trials as for those of February 24 and March 3.

TABLE 14.—*Effect of critically low artificial freezing temperatures on survival of fruit buds and differentiation in hardiness between 2 varieties of peach when frozen for 13.5 hours at the minimum, 1941*

[200 buds per sample]

Date and variety	Temperature conditions		Buds surviving from indicated tree					Significance of comparison as indicated by χ^2 test
	Minimum temperature	Rate of fall per hour	1	2	3	4	Average	
	° F.	° F.	Percent	Percent	Percent	Percent	Percent	
Mar. 25:								
Elberta	+8	6	38.0	43.0	47.0	48.0	44.0	†
Belle			40.0	43.0	51.5	56.0	47.6	
Mar. 27:								
Elberta	+8	7	57.0	68.0	61.0	70.0	62.0	*
Belle			63.0	66.0	68.0	71.0	67.0	
Apr. 3:								
Elberta	+8	5	45.0	60.0	64.0	67.0	59.0	†
Belle			50.0	54.0	55.0	65.0	56.0	
Feb. 24:								
Elberta	−4	5.3	23.5	27.0	28.5	34.0	28.3	**
Belle			33.0	34.5	38.5	49.0	38.8	
Mar. 3:								
Elberta	−3	5	6.5	17.0	19.0	19.0	15.4	**
Belle			20.0	29.5	33.0	34.5	29.3	

†Not statistically significant. *Exceeds 5-percent point. **Exceeds 1-percent point.

AIR MOVEMENT

The effect of air movement on freezing injury of fruit buds was tested by placing the samples in the freezer so that air from the fan blew directly over them. Half the samples were placed in tightly stoppered test tubes to protect the buds from drying out. The results of these tests, shown in table 15, should not be confused with previous data for test tubes in the bath. In no case was there a significant difference between the samples except for the February 6 run, when there was highly significantly less injury to exposed buds than to those sealed in the test tubes. As shown in table 7, buds on larger wood are injured less than those on average-sized shoots, and in the February 6 run the exposed shoots were composed of heavier wood than those that were not exposed. The test tubes offered no protection in themselves, and the slight air movement in the chamber caused by the fan apparently did not produce greater injury to the buds.

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TABLE 15.—*Effect of air movement on the survival of fruit buds of 3 varieties of peach when frozen artificially, 1941*

Date and variety	Temperature conditions			Relation to air current	Buds examined	Buds surviving	Significance of comparison as indicated by χ^2 test
	Minimum temperature	Rate of fall per hour	Held at minimum temperature				
Jan. 28:	° *F.*	° *F.*	*Hours*		*Number*	*Percent*	
Elberta	−4	8	15	Exposed	40	10	†
				Not exposed	177	8	
Belle	−4	8	15	Exposed	86	16	†
				Not exposed	118	13	
Jan. 31:							
Elberta	−3	8	16	Exposed	200	14	†
				Not exposed	200	12.5	
Belle	−3	8	16	Exposed	200	26	†
				Not exposed	200	20.5	
Feb. 6:							
Elberta	−2	8	16.5	Exposed	200	48.5	*
				Not exposed	200	37.5	
Belle	−2	8	16.5	Exposed	200	44.5	**
				Not exposed	200	30.5	
Feb. 10:							
Elberta	−2	8	16.5	Exposed	200	39	†
				Not exposed	200	37	
Belle	−2	8	16.5	Exposed	200	34	†
				Not exposed	200	33	
Greensboro	−2	8	16.5	Exposed	200	51	†
				Not exposed	200	52	

†Not statistically significant. *Exceeds 5-percent point. **Exceeds 1-percent point.

HARDENING OFF

Table 16 and figures 3 and 4 show the increased resistance of buds to low seasonal fluctuation in temperatures as a result of periods of relatively cold weather at different times in each season. From February 14 to 17, 1941, the maximum and minimum daily temperatures averaged +42° and +31° F., respectively. February 18 and 19 were cold with maxima of +29° and +30° and minima of +18° and +14°. Freezing runs on February 17 showed 14 percent of the Elberta buds to be alive and 32 percent of the Belle. Freezing runs on February 20 showed 56 percent and 60 percent alive for Elberta and Belle at the same minimum temperature in the freezing chamber. Hardening off of the buds occurred again in March 1941. For March 10 and 11 the average temperature was +46° and the minimum +33°. For March 12 and 13 they were +38° and +26°. Although the hardening effect is not great in this second case, it is conceivable that had the field temperatures been lower the differences would have been greater.

In 1942 the daily minimum temperatures during the hardening-off period approached 0° F., with the temperature on January 6 at −7°. It appears that the hardier Veteran is capable of hardening off somewhat more than a tender variety such as Elberta.

TABLE 16.—*Effect of hardening in the field on subsequent survival of fruit buds of 4 varieties of peach, 1941 and 1942*

[Frozen for 13.5 hours at minimum; 200 buds per tree]

Variety and date	Treatment before freezing	Temperature conditions		Buds surviving on indicated tree					Significance of comparison as indicated by χ^2 test
		Minimum temperature	Rate of fall per hour	1	2	3	4	Average	
1941		° *F.*	° *F.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Elberta:									
Feb. 17	Not hardened	−3	6	13.5				13.5	**
Feb. 20	Hardened	−3	6	61.5	53.0	55.0	55.5	56.3	
Mar. 12	Not hardened	−1	6	4.5	7.5	9.0	19.5	10.1	**
Mar. 14	Hardened	−1	6	13.0	15.0	22.5	25.5	19.0	
Belle:									
Feb. 17	Not hardened	−3	6	32.0				32.0	**
Feb. 20	Hardened	−3	6	62.0	62.5	56.5	60.5	60.4	
Mar. 12	Not hardened	−1	6	17.0	19.0	21.0	24.0	20.3	**
Mar. 14	Hardened	−1	6	34.5	44.0	49.0	53.0	45.1	
1942									
Elberta:									
Jan. 3	Not hardened	−6	5	23.5	37.5			30.5	**
Jan. 7	Hardened	−6	6	81.0	68.5			74.8	
Feb. 17	Not hardened	−6.5	7	4.0	3.0	4.0	6.5	4.4	**
Feb. 20	Hardened	−7	8	11.0	18.0	11.0	18.0	14.5	
Greensboro:									
Jan. 3	Not hardened	−6	5	65.5	67.5			66.5	**
Jan. 7	Hardened	−6	6	91.0	90.5			90.8	
Veteran:									
Feb. 17	Not hardened	−6.5	7	15.5	15.5			15.5	**
Feb. 20	Hardened	−7	8	65.0	59.0	60.5		61.5	

**Exceeds 1-percent point.

MOISTURE CONTENT OF BUDS

Toward spring of 1941 some dry-weight determinations were made of fruit buds of different varieties to study their relative size and stage of advancement. There was an indication that some relation existed between the moisture content of buds and the survival of fruit buds frozen artificially. During the 1941–42 season the studies were expanded to see whether such a relation did exist.

In order to establish a differential moisture content of the buds, shoots from two varieties were treated in three different ways on two dates. Shoots were gathered from trees in the field, brought to the laboratory, and separated into two lots. One lot was placed with the butts in water and left there for 24 or 48 hours; a second lot was placed on the table and permitted to dry for 24 or 48 hours. A third lot was brought in from the field or 2 days later, and all three sets of twigs were placed in the freezing chamber and frozen simultaneously. The results are summarized in table 17. There was a rapid loss of hardiness in the buds on shoots in the water, but the buds on shoots out of water were more hardy than the ones brought in directly from the field. Consequently, it appears that the moisture content of the buds had a greater effect on bud survival than did the temperature at which the buds were held. Holding the shoots in water increased the injury to the Elberta much more than to the Greensboro buds.

A few days later shoots of five varieties were brought to the laboratory and the butts placed in water for 24 hours. A second lot was brought directly from the field on the following day, and both groups of twigs were frozen simultaneously. As can be seen from the last part

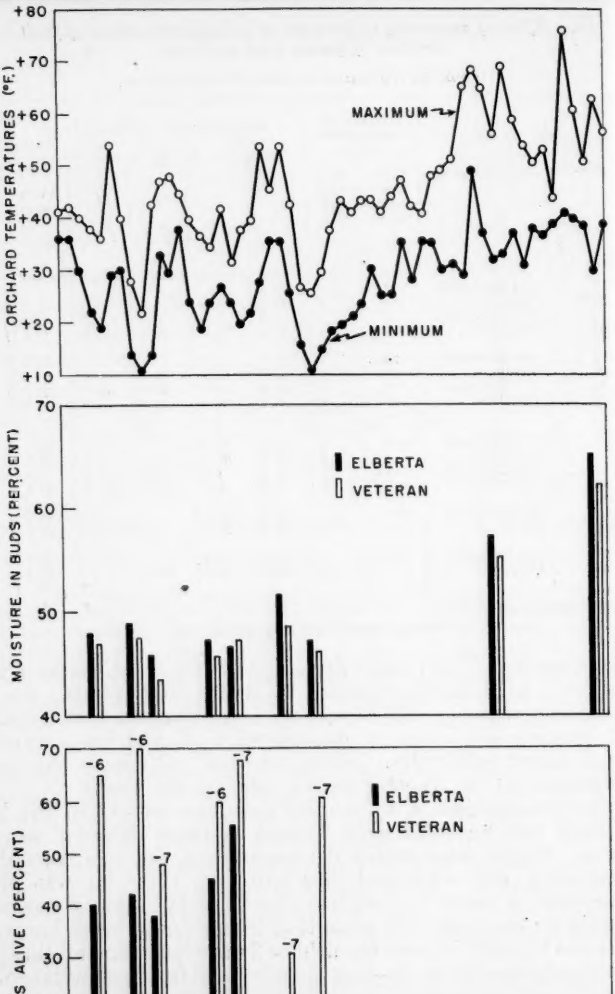

FIGURE 4.—Moisture content and survival of fruit buds of Elberta and Veteran varieties of peach as affected by fluctuation in orchard temperature when buds are frozen artificially at the minimum temperatures (°F.) shown at the top of the bars, on indicated dates, 1942.

of table 17, much more marked differences in survival of buds occurred in the lots that had been in water than in those brought directly from the field and frozen. Of greater importance is the fact that buds of Elberta and Hiley, the two varieties generally considered to have relatively tender buds, showed the greatest relative injury when frozen after being held in water. Moisture determinations made on 100 unfrozen buds of four varieties for each treatment with the buds dried at +90° C. are shown in table 17. In all cases there was more moisture present in the buds from shoots held in water.

TABLE 17.—*Effect of different treatments of the shoots on survival of fruit buds of 5 varieties of peach, 1942*

[Shoots frozen at −6° F. minimum temperature for 12 hours; 200 buds per tree]

Date and variety	Treatment of shoots at 65° F. before freezing		Rate of temperature fall per hour	Moisture content of buds	Buds examined	Buds surviving
	Held in water	Kept dry				
	Hours	*Hours*	*° F.*	*Percent*	*Number*	*Percent*
Jan. 3:						
Elberta	48	0	5	----------	400	0
	0	48	5	----------	400	63.0
	(1)	0	5	----------	400	30.5
Greensboro	48	0	5	----------	400	28.5
	0	48	5	----------	400	84.0
	(1)	0	5	----------	400	66.0
Jan. 7:						
Elberta	24	0	6	----------	400	14.5
	0	24	6	----------	400	54.0
	(1)	0	6	----------	400	75.0
Greensboro	24	0	6	----------	400	68.0
	0	24	6	----------	400	92.0
	(1)	0	6	----------	400	91.0
Jan. 13:						
Elberta	24	0	5	45.3	800	7.4
	(1)	0	5	44.4	800	62.5
Hiley	24	0	5	49.2	800	18.5
	(1)	0	5	45.5	800	86.3
Veteran	24	0	5	46.7	800	30.5
	(1)	0	5	44.9	800	88.5
Mikado	24	0	5	46.3	800	38.0
	(1)	0	5	45.8	800	85.0
Greensboro	24	0	5	----------	800	53.0
	(1)	0	5	----------	800	91.5

[1] Shoots put in freezing chamber immediately after collection from the field.

Attempts were made during the remainder of the season to obtain data on buds affected by periods of fluctuating temperature and moisture in the field. On January 16 Elberta buds with 45-percent moisture content were frozen at −7° F. for 13 hours. Of 800 buds examined from 4 trees 19 percent survived. On January 20, the day after a heavy rain, buds were frozen at −7° for 13 hours. Of 366 buds examined only 1 percent survived; the moisture content of these buds had increased to 48.3 percent. January 26 was preceded by 2 days of high temperatures, with maxima of +64° and +59°. A freezing determination made January 26 with a minimum of −6° resulted in only 7.7-percent survival in 2,000 buds from 10 trees. The moisture content of the buds before freezing was 49.1 percent. Three days later, during which time there had been cold, dry weather, buds frozen at −6° had a 40.5-percent survival and the moisture content had dropped slightly, from 49.1 to 48.3 percent.

In table 18 some data are presented on the moisture content of fruit buds of different varieties in relation to bud survival. It is clear

that there was not a close relation between bud moisture and live buds within each variety, a fact which was probably due in part to the large variation in bud survival of trees of the same variety without a correspondingly wide variation in moisture content of the buds. However, comparison of moisture content of buds and live buds for the four varieties on three different dates does show a highly significant negative correlation of −0.876, indicating that in those varieties in which the moisture content of the buds increased most, fewer buds survived the freezing temperature. The correlations were computed from the individual-tree data and not from the averages, which might tend to increase the values. The dry weight of 100 buds per tree is included to show that there was very little if any change in bud size.

TABLE 18.—*Dry weight, moisture content, and bud survival of artificially frozen fruit buds of 4 varieties of peach, 1942*

[Rate of temperature fall 8° F. per hour; kept at minimum temperature for 15 hours; 200 buds per sample]

Variety and tree	Jan. 29 [1]				Feb. 10 [1]				Mar. 10 [1]			
	Minimum temperature	Dry weight	Moisture content	Buds surviving	Minimum temperature	Dry weight	Moisture content	Buds surviving	Minimum temperature	Dry weight	Moisture content	Buds surviving
Elberta:	° F.	*Grams*	*Percent*	*Percent*	° F.	*Grams*	*Percent*	*Percent*	° F.	*Grams*	*Percent*	*Percent*
15–7	−6	0.813	48.5	37.5	−6	0.830	47.8	52.0	−4	0.922	56.5	0
15–10	−6	.865	48.8	45.0	−6	.768	47.3	42.5	−4	.885	58.0	0
15–11	−6	.839	48.4	41.0	−6	.874	46.8	51.5	−4	.871	58.4	0
15–18	−6	.826	47.7	38.5	−6	.840	48.5	35.0	−4	.781	59.1	0
Average	−6	.836	48.4	40.5	−6	.828	47.6	45.3	−4	.865	58.0	0
Golden Jubilee:												
SW	−6	.928	48.4	38.5	−6	.882	46.7	50.0	−4	1.020	55.2	1.0
NE	−6	.873	47.4	23.0	−6	.976	46.3	27.5	−4	.979	55.1	1.5
SE	−6	.928	47.5	45.5	−6	.955	46.5	37.0	−4	.908	56.0	0
NW	−6	.918	46.2	38.0	−6	.895	45.7	49.0	−4	.924	54.6	1.0
Average	−6	.912	47.4	36.3	−6	.927	46.3	40.9	−4	.958	55.2	.9
Veteran:												
SW	−6	.768	48.1	65.5	−6	.817	46.9	53.5	−4	.800	57.5	7.5
NE	−6	.864	45.2	63.5	−6	.814	44.7	64.0	−4	.910	53.7	6.5
SE	−6	.860	47.6	74.0	.....	.....	.....	.....	−4	.835	57.1	7.0
17	−6	.857	46.7	57.5	.....	.....	.....	.....	−4	.812	55.2	8.0
Average	−6	.837	46.9	65.1	−6	.816	45.8	58.8	−4	.839	55.9	7.3
Eclipse:												
SW	−6	1.043	46.4	79.5	−6	1.252	43.9	56.0	−4	1.085	53.2	2.5
NE	−6	1.075	47.1	73.5	−6	1.269	44.6	65.5	−4	1.078	53.5	5.5
SE	−6	1.058	46.7	80.5	−6	1.144	42.1	73.5	−4	1.096	54.8	3.0
NW	−6	1.028	46.9	77.5	−6	1.027	45.4	63.0	−4	1.117	55.1	3.0
Average	−6	1.051	46.8	77.8	−6	1.173	44.0	64.5	−4	1.094	54.2	3.5

[1] Correlation between moisture and survival of buds: For Jan. 29, Feb. 10, and Mar. 10, −0.876 (P>1 percent); for Jan. 29 and Feb. 10, −0.473 (P>1 percent).

Table 19 and figure 4 show the seasonal relation between Elberta and Veteran for dry weight, moisture content, and survival of artificially frozen fruit buds. There was a highly significant negative correlation between moisture content of fruit buds and bud survival. Apparently there is considerable fluctuation in moisture on the fruit-bud tissues during the dormant period. It appears that the moisture content of the buds of the tenderer variety, Elberta, changes more rapidly and to

a greater extent than that of the relatively hardy variety, Veteran. Although there was a big increase in moisture content of the buds from February 24 to March 10, there was very little evidence of any change in dry weight of the buds. On March 20, however, there was a noticeable increase in dry weight of the buds, indicating that growth had occurred in the 10-day period prior to March 20. Elberta buds frozen on this date were so badly injured that the stamens, pistil, and bud scales all showed about the same degree of browning. On the other hand, the injured anthers of Veteran buds still retained some of their yellow cast.

TABLE 19.—*Dry weight, moisture content, and bud survival of artificially frozen fruit buds of Elberta and Veteran peaches, 1942*

[Rate of temperature fall 8° F. per hour; kept at minimum temperature for 12 hours]

Date	Minimum temperature	Elberta [1] [2]			Veteran [2] [3]		
		Dry weight	Moisture content	Buds surviving	Dry weight	Moisture content	Buds surviving
	°F.	*Grams*	*Percent*	*Percent*	*Grams*	*Percent*	*Percent*
Jan. 29	−6	0.836	48.3	40.5	0.837	46.9	65.2
Feb. 2	−6	.827	48.9	41.7	.843	47.4	70.2
Feb. 4	−7	.884	46.3	38.1	.835	43.4	48.3
Feb. 10	−6	.828	47.6	45.2	.815	45.8	58.7
Feb. 12	−7	.884	47.2	55.8	.843	47.5	68.3
Feb. 17	−6.5	.800	52.3	4.4	.867	49.0	31.4
Feb. 20	−7	.769	47.6	14.5	.847	46.7	61.6
Feb. 24	−7	.840	47.0	33.0			
Mar. 10 [4]	−4	.865	58.0	0	.839	55.9	7.2
Mar. 20	0	1.237	66.3	0	1.044	63.6	2.3

[1] 4 trees with 200 buds examined from each.
[2] Correlation between moisture and live buds: For both varieties, −0.922 ($P>1$ percent); for Elberta, −0.755 ($P>5$ percent); for Veteran, −0.832 ($P>1$ percent).
[3] 2 trees with 200 buds examined from each except on Jan. 29, Mar. 10, and Mar. 20 when 4 trees were used.
[4] On Mar. 4 to 7, inclusive, the maximum temperature was 45° F.; on Mar. 8 and 9 it was 66°.

VARIETY

Of the relatively few varieties surveyed, at least 2 trees and usually 4 were available for sampling. For the most part, trees of the same variety possessed fairly comparable wood and the size of shoots used was typical for the variety. As there was a difference in bud set on the different varieties, 15 to 18 shoots of Elberta were required to furnish 200 buds for a test reading, whereas only 9 to 11 shoots of Greensboro and Cumberland were needed to furnish samples of that size. Elberta was included in nearly all the freezing determinations of varieties, since its fruit buds are among the most susceptible to cold injury of any tested, when considered throughout the seasonal range. The results of these freezing trials with varieties are shown in table 20.

During the 1940 dormant season it was evident that Mikado, Carman, and Belle fruit buds were the hardiest of those tested and that in general Hiley and Elberta were among the tenderest. It should be noted that in some instances the varietal differences were not clear-cut, partly because a critically low freezing temperature was not used. Because of the type of freezing chamber employed in 1940, it was not possible to change the temperature quickly to correspond with change in the relative hardiness of the buds as they became progressively more tender.

TABLE 20.—*Hardiness of artificially frozen fruit buds of peach varieties, 1940–42*

[200 buds per tree]

Date	Temperature conditions: Minimum temperature	Temperature conditions: Rate of fall per hour	Temperature conditions: Held at minimum temperature	Variety	Buds surviving on indicated tree: 1	2	3	4	Average	Significance of comparison as indicated by χ^2 test
1940	° *F.*	° *F.*	*Hours*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
				1. Rochester	24.5	27.0	34.5	------	28.7	
				2. Lemon Free	44.5	41.5	52.0	------	46.0	1, 2**
				3. Hiley	60.5	56.5	49.0	------	55.3	2, 3**
Feb. 15	+9.5	(1)	17	4. Admiral Dewey	67.5	63.5	------	------	65.5	3, 4**
				5. Golden Jubilee	70.0	64.0	67.5	72.5	68.5	4, 5†
				6. Veteran	64.0	72.0	75.5	63.0	68.6	5, 6†
				7. Greensboro	76.5	85.0	76.5	77.5	78.9	6, 7**
				8. Mikado	88.5	82.5	88.0	79.0	84.5	7, 8**
				1. Hiley	39.0	33.5	41.0	------	37.8	
				2. Early Wheeler (Red Bird)	55.5	55.0	48.5	54.0	53.3	1, 2**
				3. Elberta	55.5	64.0	60.5	43.0	55.8	2, 3†
				4. Cumberland	57.5	59.5	51.5	59.0	56.9	2, 4†
				5. Veteran	60.0	69.0	50.0	50.5	57.4	2, 5†
26	+8.5	(1)	15	6. Golden Jubilee	61.5	62.5	62.0	50.5	59.1	2, 6*
				7. Greensboro	61.0	59.0	66.5	50.5	59.3	2, 7*
				8. Eclipse	57.0	65.5	48.0	73.0	60.9	3, 8*
				9. Belle	53.5	64.5	72.5	66.5	64.3	7, 9*
				10. Carman	66.0	73.0	66.0	73.0	69.5	9, 10*
				11. Mikado	74.0	69.5	79.5	83.5	76.6	10, 11**
1941										
				1. Elberta	28.5	27.0	34.0	23.5	28.3	
Feb. 24	−4	5.3	13.5	2. Hiley	47.0	33.0	25.0	------	35.0	1, 2**
				3. Belle	38.5	33.0	49.0	34.5	38.8	2, 3†
				1. Elberta	4.0	7.0	9.0	12.0	8.0	
				2. Cumberland	16.5	16.0	16.5	22.0	17.8	1, 2**
				3. Greensboro	32.0	29.5	37.0	51.5	37.5	2, 3**
26	−4	5.3	13.5	4. Eclipse	43.5	39.0	29.5	44.0	39.0	3, 4†
				5. Golden Jubilee	48.0	45.0	37.5	40.5	42.8	4, 5†
				6. Admiral Dewey	53.5	63.5	------	------	58.5	5, 6**
				7. Veteran	60.5	64.0	------	------	62.3	6, 7†
				1. Elberta	17.0	6.5	19.0	19.0	15.4	
Mar. 3	−3	5	13.5	2. Hiley	27.5	19.0	28.0	------	24.8	1, 2**
				3. Belle	34.5	29.5	20.0	33.0	29.3	2, 3†
				1. Elberta	3.0	3.0	2.0	1.0	2.3	
5	−3	6.2	13.5	2. Belle	4.0	5.5	3.0	9.5	5.5	1, 2**
				3. Mikado	5.0	11.0	19.5	11.0	11.6	2, 3**
				4. Fair Beauty	32.5	41.5	------	------	37.0	3, 4**
				1. Elberta	24.5	43.5	28.0	27.0	30.8	1, 2†
				2. Belle	26.5	35.0	38.0	40.0	34.9	2, 3†
10	−1	5.4	13.5	3. Hiley	------	33.5	37.0	40.5	37.0	1, 3**
				4. Cumberland	30.5	38.0	49.0	36.0	38.4	2, 4†
				5. Eclipse	55.5	58.0	57.5	62.0	58.3	4, 5**
				6. Veteran	52.5	64.0	------	------	58.3	4, 6**
				1. Hiley	------	32.0	31.0	39.0	34.0	
				2. Belle	55.0	54.0	50.0	65.0	56.0	1, 2**
				3. Cumberland	66.0	71.0	40.0	56.0	58.3	2, 3†
Apr. 3	+8	5.1	13.5	4. Elberta	60.0	64.0	70.0	45.0	59.8	2, 4†
				5. Eclipse	58.0	61.0	77.0	61.0	64.3	4, 5*
				6. Greensboro	70.0	70.0	65.0	64.0	67.3	5, 6†
				7. Golden Jubilee	76.0	77.0	69.0	73.0	73.8	6, 7**
				1. Hiley	------	4.0	2.0	2.5	2.8	
7	+8	5	13.5	2. Elberta	6.0	1.0	23.0	17.0	11.8	1, 2**
				3. Belle	16.5	8.0	38.5	43.5	26.6	2, 3**
1942										
				1. Golden Jubilee	38.5	23.0	45.5	38.0	36.3	
				2. Elberta	37.5	45.0	41.0	38.5	40.5	1, 2†
				3. Hiley	52.0	43.5	53.0	------	49.5	2, 3**
				4. Mikado	56.5	61.5	54.5	52.5	56.3	3, 4*
Jan. 29	−6	8	15	5. Cumberland	56.5	57.5	------	------	57.0	3, 5*
				6. Veteran	65.5	63.5	74.0	57.5	65.1	5, 6**
				7. Carman	78.0	66.0	------	------	72.0	6, 7*
				8. Greensboro	79.0	69.0	------	------	74.0	6, 8**
				9. Eclipse	79.5	73.5	80.5	77.5	77.8	8, 9†
				1. Elberta	0	0	0	0	0	
Mar. 10	−4	8	15	2. Golden Jubilee	1.0	1.5	1.0	0	.9	
				3. Eclipse	2.5	5.5	3.0	3.0	3.5	2, 3**
				4. Veteran	7.5	6.5	7.0	8.0	7.3	3, 4**

[1] Shoots put directly at minimum temperature.

†Not significantly different.

*Exceeds 5-percent point.

**Exceeds 1-percent point.

In 1941 a number of comparisons were made at different times. Admiral Dewey, Veteran, and Eclipse were among the hardiest, and Hiley and Elberta were again relatively tender. It is of interest to note the change in relative hardiness of Hiley. Until March 3 Hiley was as hardy as Belle and much hardier than Elberta. When the buds became tender as they approached bloom, however, Hiley buds became much more tender than those of Elberta or Belle.

In the 1942 season the varietal hardiness as evaluated by artificial freezing showed the same relative order as in the two previous seasons, with Greensboro, Veteran, and Eclipse relatively hardy and Elberta and Hiley tender.

Unless the freezing temperature is low enough to kill all but 10 to 20 percent of the fruit buds of a tender variety, it is doubtful whether a 5- to 10-percent difference in survival between varieties is of any great significance in artificial freezing. The results indicate that by artificial-freezing methods it might be possible to classify peach varieties into three categories: (1) Those relatively tender, such as Hiley and Elberta; (2) those relatively hardy, such as Greensboro, Mikado, and Veteran, the buds of which were usually the most cold-resistant during most of the dormant season; and (3) those intermediate between the extremes, such as Belle, Cumberland, and Golden Jubilee.

DISCUSSION

In this work certain factors have been studied in relation to the hardiness of fruit buds of peaches when frozen artificially.

Detection of injury to the fruit buds of peaches by means of electrical conductance was unsatisfactory, although Dexter, Tottingham, and Graber (*13*), working with alfalfa roots, and Stuart (*48*), working with apples, found the method reliable. Exosmosis from peach buds apparently does not take place as readily or as uniformly as it does from tissue of stems and roots of plants such as apple and alfalfa for which the method has been found valuable in studying hardiness. When peach buds were sliced longitudinally, release of electrolytes was greatly increased, but that is to be expected because of the larger surface area of tissue and cut cells that was directly in contact with water. Consequently, it is not clear whether the poor release of electrolytes was due to the bud scales preventing escape of the salts or to the fact that exosmosis did not take place from the frozen tissue. At the temperatures used, in most cases only the tissues of the pistil were injured and the enveloping floral parts and bud scales were uninjured.

Injured fruit buds can be detected rather easily by examining tissue of the floral parts for browning. Usually injury can be detected first in oxidation of tissue of the pistil. Examination of the buds can be made quickly, and the data on the number of injured and uninjured buds can be recorded on a calculating machine.

In making a study of factors affecting fruit-bud injury it is necessary to have adequate-sized samples because of the variability that is apt to occur and the fact that the data are of a discrete nature. In this study it was decided to use from 150 to 200 buds per tree in a sample. It was found in sampling different-sized shoots from a tree that buds

on small, thin twigs were injured more severely at a critical freezing temperature than were those on medium-sized wood.

It is evident that a slow rate of freezing causes less injury than a relatively fast change in temperature, as has been shown by others. Data presented show that with a slow rate of freezing peach buds will survive at a much lower minimum temperature than would otherwise be the case. This has been shown also by Meader and Blake (*37*). By freezing the buds slowly it seems to be possible to differentiate more clearly between tender and semitender varieties, probably because it is possible to approach the critical minimum temperature of the tender variety more closely and still not kill all the buds.

If the buds remain at an injuriously low temperature for a considerable length of time, more injury is apt to occur than if they are exposed to the minimum temperature for only a few minutes. This agrees with results obtained by Potter (*41*), Hildreth (*25*), and Field (*20*) in their work with apples. When varieties are to be compared, it is essential that the buds be exposed to the minimum temperature for the same length of time.

When a critical minimum temperature is approached, a higher or lower temperature of 1° F. causes a relatively large change in fruit-bud survival in both tender and hardy varieties. Consequently, there does not appear to be a very wide range in cold hardiness between so-called hardy and tender varieties of peaches. If the bud set of a variety is taken into consideration, however, there may be a relatively wider spread in hardiness between varieties as measured by crop performance when observed under field conditions. McMunn (*35*) noted such a condition in observations of hardiness of peach varieties in the field. A 90-percent loss of fruit buds on Cumberland, a variety that sets a large number of buds on each shoot, would leave an ample number for a crop, whereas such a loss on Elberta, a less abundant bud producer, might leave enough buds for only a light crop. The vegetative condition of a tree may influence bud hardiness, depending on the type of twig growth. If all the buds were borne on small twigs, there might be a complete crop loss from low temperature, but if the buds were on larger wood, they might survive.

Since diurnal temperatures fluctuate and low temperature in the field causes a hardening off of fruit buds, freezing data on relative hardiness of two varieties frozen on separate occasions are not directly comparable. In any comparison of varietal hardiness it is desirable, therefore, to use at least one control variety of known characteristics in all determinations to serve as a basis for evaluating varieties frozen at different times. Even then, there is the possibility that all varieties will not respond in the same way to changes in environmental conditions. Thus, Elberta was more tender on March 14 than on March 7, but Belle was hardier on March 14 than on March 7 (table 6). Meader and Blake (*37*) encountered similar conditions in New Jersey. It is interesting to note that cold resistance fluctuates rather widely during the dormant season for hardy as well as for tender varieties, a condition also noted by Meader and Blake (*37*). This may account for differences in reports on varietal hardiness based on field observations made after a single freeze.

Associated with the fluctuation in hardiness of buds is a change in moisture content of the buds even during the dormant season. It appears from the studies reported here that an increase in moisture content of the buds is apt to be reflected in greater injury when the buds are subjected to critically low temperatures. When Chandler (*7*) sawed off limbs of peach trees and suspended them among the other branches, the buds in a wilted or semiwilted condition proved more resistant to low temperature than the normal turgid ones. Hildreth (*25*) studied the moisture content of two apple varieties throughout the winter. The content of the hardy one remained practically constant, but that of the tender one fluctuated. Strausbaugh (*47*) found that the moisture content of a semihardy plum fluctuated during the dormant period, dropping at low temperatures and rising at high ones. In the case of a hardy variety it remained fairly constant, irrespective of environmental changes. There is an indication that tender peach varieties may have a more rapid and wider fluctuation in moisture content than hardy ones, but this phase of the work needs more study.

From the results reported it appears that the hardiness of fruit buds of peaches can be evaluated by artificially freezing them and that this method probably can be used to good advantage in studying varietal hardiness or inheritance of cold resistance in peaches, provided the methods are standardized. It should be evident that, because of the many factors which may influence the amount of injury sustained by the fruit buds, a comparison of the relative hardiness of varieties after a natural freeze in the field is a rough evaluation at best.

SUMMARY

Freezing of peach fruit buds was investigated during the dormant periods of three seasons, beginning with the winter of 1939–40.

Electrical conductivity was tried as a means of detecting injury to the floral parts of artificially frozen peach buds, but the method was unsatisfactory. The visible browning of frozen tissue was used, therefore, for determining injury.

The influence of the following factors on bud survival was studied: Size of shoots, rate of freezing, minimum temperature, length of time buds were left at minimum temperature, hardening-off effect of low field temperatures, moisture content of buds, and seasonal trend of fruit-bud hardiness. Of these factors the ones that were found most apt to cause injury to the fruit buds were a rapid rate of temperature fall; a low minimum temperature, provided the temperature was in the critical range for bud killing; and field environmental conditions, such as warm temperatures preceding freezing or high moisture content of buds which causes them to be susceptible to low-temperature injury. Low field temperatures increased the cold resistance of the buds in both hardy and tender varieties. High field temperatures, especially toward the end of the dormant season, seemed to make tender some varieties, such as Hiley, more than it did others.

There was a fluctuation in the hardiness of peach fruit buds in the early part of the winter while the buds were dormant. The buds did not become more susceptible to low-temperature injury as the season

advanced unless some days were warm. Warm weather, particularly if wet, made the fruit buds more tender. Under such conditions some varieties that had been relatively cold-hardy in the early part of the dormant season became relatively tender. Other varieties, notably Greensboro and Veteran, seemed to be relatively hardy throughout the entire season.

Suggestions are presented concerning factors that should be considered in comparing the cold hardiness of varieties or in studying by artificial freezing the inheritance of cold resistance in fruit buds of peach.

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CLOCKWISE AND COUNTERCLOCKWISE SPIRALITY IN THE PHYLLOTAXY OF TOBACCO[1]

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INTRODUCTION

Only two species of tobacco, *Nicotiana tabacum* L. and *N. rustica* L., have found an important place in cultivation for chewing or smoking purposes. *N. rustica* is now of little importance in agriculture, having been supplanted by *N. tabacum* except in parts of Poland, Union of Soviet Socialist Republics, Asia Minor, and India. In both of these species the fundamental arrangement of the leaves always follows a clockwise or a counterclockwise spiral course from the cotyledons to the inflorescence around the stem.

A previous study (*1*)[2] involving comparatively few tobacco plants indicated that the spirality of about half the plants was clockwise and that of the other half was counterclockwise. It was suggested, however, that the proportion of the plants of either type might be changed by breeding and rigid selection. To test this hypothesis the direction of the spirals of several thousand tobacco plants, including the progeny from selected clockwise and counterclockwise parents, was determined in 1944 and 1945.

The spiral course always follows from older to younger leaves up the stem. To avoid confusion it is important to define precisely the clockwise and counterclockwise directions. In this paper, as in a previous one by the writer (*1*), the same procedure has been consistently followed in defining the clockwise and counterclockwise arrangements. If a string is wound around the stem to connect the consecutively younger leaves, the visible sections in the clockwise spirality will incline upward from right to left. In the counterclockwise spirality the visible sections will run up the stem from left to right.

In tobacco one course or the other is normally followed throughout the entire leaf arrangement of the main stem of the plant. Occasionally a node may show a whorled arrangement of the leaves, but this is exceptional and in some instances appears to be due to the failure of the internode to elongate. The writer has observed on the main stem no instance of the reversal of the spiral from that which began above the cotyledons. The leaf arrangement of the branches and suckers, however, may show an entirely independent behavior with respect not only to the spiral course but also to the leaf arrangement itself as expressed in the Fibonacci system. The alternate arrangement of the leaves in tobacco, unlike that of many other plants, is

[1] Received for publication May 31, 1945.

[2] Italic numbers in parentheses refer to Literature Cited, p. 244.

constant and becomes established as soon as the first leaf appears above the cotyledons, whichever the direction of the spirality may be. As shown in figure 1, the cotyledons alone are opposite in position.

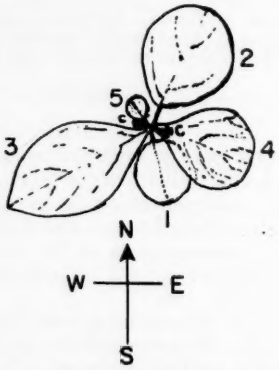

FIGURE 1.—Diagrammatic drawing of Maryland Mammoth seedling with counterclockwise spirality as seen from above. Note cotyledons (*c*) and five leaves (1–5). The cotyledons (*c*) are very small, situated beneath all the leaves 1 to 5, and in line with the axis of leaf 4. Leaf 1 (oldest): blade 1 cm. long, 8 mm. wide; petiole 3 mm. long. Leaf 2: blade 1.5 cm. long, 1.4 cm. wide; petiole 3 mm. long. Leaf 3: blade and petiole 2.5 cm. long, greatest width 1.5 cm. Leaf 4: blade and petiole 1.5 cm. long, greatest width 1.2 cm. Leaf 5: very small.

Tobacco is distinctive in the constancy of its alternate leaf arrangement above the cotyledons in comparison with low ragweed (*Ambrosia artemisiifolia* L.), for instance. Whereas low ragweed maintains the opposite arrangement for six or eight nodes above the cotyledons themselves before the alternate arrangement and spirality are initiated, tobacco initiates the spiral arrangement as soon as the first leaf appears above the cotyledons.

FREQUENCY OF CLOCKWISE AND COUNTERCLOCKWISE SPIRALITY

During 1944 and 1945 the direction of the spirals of the leaves of 23,507 tobacco plants was determined. Of these, 19,406 plants belonged to the species *Nicotiana tabacum* and 4,101 to *N. rustica*, of which there were 14 strains. Of the 19,406 plants of *N. tabacum*, 12,026 were original Maryland Mammoth, 4,328 were Connecticut Broadleaf, 149 were a cigar type grown in the Dominican Republic, and 2,903 consisted of 5 varieties or strains of Maryland tobacco. This figure includes plants of Standup Maryland Mammoth, a variety with nonflowering Maryland Mammoth habit, originating from the cross Maryland Mammoth × White Burley.

Of the total 12,026 plants of the original Maryland Mammoth group included in this study, 1,696 were counted at Marlboro, Md., by an examination of the stalks of fully grown plants which had been harvested and stripped and 10,330 were counted in the seedling stage. The latter were the progenies of 6 parent plants, 3 of which

(plants 2, 3, and 4) were clockwise in their leaf arrangement and 3 (plants 1, 5, and 6) were counterclockwise. The progenies of the 3 clockwise parents comprised 3,971 plants and those of the 3 counterclockwise ones 6,359 plants.

The data for the different varieties and strains of *Nicotiana tabacum* are presented in table 1. As shown, three Maryland Broadleaf strains, Catterton, Robinson, and Wilson, were grown under two different conditions of fertilization with fertilizer of a 4–8–12 formula. One was a treatment at the rate of 750 pounds per acre; the other was at the rate of 2,000 pounds per acre.

TABLE 1.—*Occurrence of clockwise and counterclockwise plants in several varieties and strains of Nicotiana tabacum*

[Field plants grown at Marlboro, Md., with 4–8–12 fertilizer, applied at different rates per acre]

Variety and type of plant and treatment	Plants in sample	Plants with spiral—		Expected mean	χ^2	Probability of occurrence
		Clockwise	Counterclockwise			
Field-grown Catterton Maryland Broadleaf:	*Number*	*Number*	*Number*	*Number*		
2,000 pounds fertilizer per acre	309	143	166	154.5	1.71	0.10–0.20
750 pounds fertilizer per acre	383	182	201	191.5	.94	.30–.50
Total	692	325	367	346	2.55	.10–.20
Field-grown Robinson Maryland Broadleaf:						
2,000 pounds fertilizer per acre	373	180	193	186.5	.45	.50–.70
750 pounds fertilizer per acre	307	134	173	153.5	4.95	.02–.05
Total	680	314	366	340	3.98	.02–.05
Field-grown Wilson Maryland Broadleaf:						
2,000 pounds fertilizer per acre	308	140	168	154	2.55	.10–.20
750 pounds fertilizer per acre	299	146	153	149.5	.16	.20–.30
Total	607	286	321	303.5	2.02	.10–.20
Field-grown Maryland Broadleaf No. 1 (cross)	318	152	166	159	.62	.30–.50
Field-grown Standup Maryland Mammoth	606	295	311	303	.42	.50–.70
Seedling cigar-type tobacco from Dominican Republic	149	75	74	74.5	.007	.90–.95
Seedling Connecticut Broadleaf	4,328	2,173	2,155	2,164	.074	.70–.80
Field-grown Maryland Mammoth	1,696	833	863	848	.53	.30–.50
Seedling Maryland Mammoth	10,330	5,165	5,165	5,165	0	.99+
Grand total	19,406					

An inspection of the data on the occurrence of clockwise and counterclockwise plants in the various samples, in comparison with the expected numbers and the χ^2 determinations, indicates clearly that the observed differences in the number of clockwise and counterclockwise plants follow a 50:50 ratio; the goodness of fit as indicated by the χ^2 values is high.

In table 2 data on the occurrence of plants with clockwise and counterclockwise spirals in strains of *Nicotiana rustica*, χ^2 calculations, and similar information are presented. The χ^2 values indicate that clockwise and counterclockwise plants approximate the 50:50 ratio shown for the varieties and strains of *N. tabacum* analyzed in table 1.

TABLE 2.—*Occurrence of clockwise and counterclockwise plants in 14 strains of Nicotiana rustica*

Strain	Plants in sample	Plants with spirals—		Expected mean	χ^2	Probability of occurrence
		Clockwise	Counterclockwise			
	Number	*Number*	*Number*	*Number*		
34753 [1]	858	450	408	429	2.06	0.10–0.20
Mammoth No. 4259	580	284	296	290	.25	.50–.70
Brasilia No. 23	287	140	147	143.5	.17	.50–.70
Line 5.2.1	610	330	280	305	4.10	.02–.05
Olson selection	265	133	132	132.5	.004	.90–.95
Olson 68	322	152	170	161	1.01	.30–.50
M (2)	149	73	76	74.5	.06	.80–.90
4390–1	141	67	74	70.5	.35	.50–.70
4398–1	149	82	67	74.5	1.51	.20–.30
4399–1	139	67	72	69.5	.18	.50–.70
43101–1	143	73	70	71.5	.06	.80–.90
43102–1	155	79	76	77.5	.06	.80–.90
43104–1	152	84	68	76	1.68	.10–.20
43105–5	151	74	77	75.5	.06	.80–.90
Total	4,101	2,088	2,013	2,050.5	1.37	.20–.30

[1] Accession number of Division of Plant Exploration and Introduction, U. S. Department of Agriculture. All other numbers are those of the Division of Tobacco Investigations.

Table 3 presents an analysis of the progenies of six selfed Maryland Mammoth plants selected on the basis of their different spiral leaf arrangements. Plants 2, 3, and 4 had clockwise spirals, and plants 1, 5, and 6 counterclockwise spirals. From the χ^2 values it is obvious that the two types of spirals occurred in a 50:50 ratio in the progenies regardless of the direction of the parental spiral, and the heterogeneity tests confirm this conclusion. It is indicated in this instance that regardless of the spirality of the parents selected and inbred there has been no significant departure from the 50:50 ratio of spirality.

TABLE 3.—*Heterogeneity of the F_1 progenies of 3 selected clockwise-spiral and 3 selected counterclockwise-spiral plants of Maryland Mammoth tobacco*

Parent characteristic and No.	Progenies in sample	Progenies with spirals		Expected mean	χ^2	Degrees of freedom	Probability of occurrence
		Clockwise	Counterclockwise				
Clockwise parent:	*Number*	*Number*	*Number*	*Number*			
2	1,860	981	879	930	5.594	1	0.01–0.02
3	148	69	79	74	.676	1	.30–.50
4	1,963	978	985	981.5	.025	1	.80–.90
Total	3,971	2,028	1,943	1,985.5			
Deviation χ^2					1.819	1	.10–.20
Heterogeneity χ^2					4.476	2	.10–.20
Total χ^2					6.295	3	.05–.10
Counterclockwise parent:							
1	2,062	1,021	1,041	1,031	.194	1	.50–.70
5	2,148	1,068	1,080	1,074	.067	1	.70–.80
6	2,149	1,048	1,101	1,074.5	1.307	1	.20–.30
Total	6,359	3,137	3,222	3,179.5			
Deviation χ^2					1.136	1	.20–.30
Heterogeneity χ^2					.432	2	.80–.90
Total χ^2					1.568	3	.50–.70
Grand total	10,330	5,165	5,165	5,165	0	1	.99+

Other investigators have found very close approximation to the 50:50 ratio in the occurrence of clockwise and counterclockwise spirality in different plants. Macloskie (*9*), studying the arrangement of the flowers of *Spiranthes praecox* (Walt.) Wats. and Coult., and Koriba (*7*), studying those of *S. australis* Lindl., found an equality of ratio to exist.

DeVries (*4, v. 2, p. 561*) studied the frequencies of the clockwise and counterclockwise spirals of the stems of *Dipsacus sylvestris* Huds. and found that in 484 plants 245 were right-handed and 239 left-handed, which is a very close approximation to a 50:50 ratio. These figures, representing the offspring of two successive years, indicated that there had been no transmission of the characters.

Ikeno (*5*), studying *Plantago major* L. var. *asiatica* (L.) Decne. f. *contorta* Makino, found equality of ratio in the torsion of the leaves and concluded that the individual variation in spirality was not inherited but persisted as a fluctuating character.

Davies (*3*) found that in 500 plants of *Ailanthus altissima* (Mill.) Swingle 258 were clockwise in spirality and 242 counterclockwise, a very close approximation to a 50:50 ratio.

Cook (*2*) reported equality of ratio in the right- and left-handed spirals of the scales of the cones of *Pinus austriaca* Hoess (*P. nigra* Arnold var. *austriaca* (Hoess) Aschers. and Graebn.) and *P. pumilio* Haenke (*P. mugo* Turra var. *pumilio* (Haenke) Zenari).

Lugard (*8*), studying Egyptian cottons, concluded that neither the clockwise nor the counterclockwise spirality of the leaves of the main stem was inherited and that the branches did not follow the phyllotaxy of the main stem.

Imai (*6*) in Japan studied the spirality of the sweetpotato (*Ipomoea batatas* (L.) Lam.) and that of the Japanese morning-glory (*Pharbitis nil* Choisy [*Ipomoea nil* (L.) Roth]). He found a ratio very close to 50:50 prevailing in both species. Of a progeny of 1,018 plants from a right-handed parent of the Japanese morning-glory, 518 were right-handed and 500 left-handed. Of 1,463 plants from a left-handed parent, 733 were right-handed and 730 left-handed. Imai found no evidence of inheritance of either type of spirality from selected parents. Moreover, he found no relation between the twining behavior of the morning-glory and the spiral arrangements of its leaves, since the latter character is determined much earlier than twining. He also studied the spirality of the branches of an oak tree (*Quercus vibrayeana* Franch. and Sav.); of 200 branches studied, 92 were right-handed and 108 left-handed. Since χ^2 in this instance is only 1.28, it is obvious that the ratio tends to be a 50:50 one. Imai concluded that the dimorphism of spirality as expressed in the alternate leaf arrangement is of general occurrence, is not inherited, and has a random expression or tends closely toward a 50:50 ratio.

From the general occurrence of the 50:50 ratio of clockwise and counterclockwise spirality in other plants, it is obvious that this ratio in tobacco is a normal expression and there has been no indication of significant departure from it whether the parent plants were clockwise or counterclockwise in their leaf arrangement.

SUMMARY

The spiral arrangement of the leaves of two species of tobacco, *Nicotiana tabacum* and *N. rustica*, was studied. Spirality was determined in 23,507 plants of different varieties and strains of both species. The distribution of the observed frequencies of the clockwise and counterclockwise courses in the various samples was subjected to the χ^2 tests to determine the significance of the results, or the goodness of fit. The χ^2 values indicated that all the samples were drawn from populations having a 50:50 ratio. This appears to be an inherent condition in tobacco as in other plants studied so far.

It does not appear that selected parents of Maryland Mammoth tobacco transmitted any of their individual characteristics of spirality to their progenies. The distribution of these two spiral alternatives so far as observed is fundamentally one of chance.

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STORAGE QUALITY OF APPLES IN RELATION TO SOIL APPLICATIONS OF BORON[1]

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INTRODUCTION

Boron has been found to be deficient in the soils of some apple orchards, and the deficiency has shown up in the fruit as a physiological disorder generally referred to as internal cork but also called corky core and drought spot. Relatively small applications of boron to the soil have corrected such deficiencies of apple trees and other plants, but in concentrations greater than necessary to correct deficiencies boron may become toxic. Because of the great physiological effects of boron, a study of its influence on the response of apples in storage seemed desirable.

In considering the influence of boron on apples it is important to know whether a given treatment changes the boron status of a tree from a deficiency to a sufficiency or from a sufficiency to an excess. The fruit appears to be a sensitive index to the boron status of a tree, because boron accumulates in higher percentages in the fruit than in other parts (*2*) [2] and it is also more subject to injury from a deficiency or an excess of boron.

Boron deficiency in soils of apple orchards is generally indicated by internal cork in the fruit. Askew and Thomson (*1*) found that apples from sections where internal cork did not develop had a boron content ranging from 10 to 27 p. p. m. (dry-weight basis) whereas those from sections where internal cork occurred contained only 4 to 10 p. p. m. Woodbridge (*13*) stated that less than 6 to 7 p. p. m. of boron in the fruit may constitute a serious deficiency. Magness and Batjer [3] found that fruit of the Ben Davis variety seriously affected with internal cork had a boron content of 5 p. p. m. or less whereas trees of this variety on which the fruit did not develop this disorder contained 8 p. p. m. or more of boron. Where internal cork was prevalent in apples from certain limbs but not in those from others on the same tree they observed that the boron content of the fruit from limbs producing corky fruit was less than 5 p. p. m., whereas in fruit from the limbs producing cork-free fruit it was 8 p. p. m. or more. Thus, the same relation of boron content of fruit to internal cork existed

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[2] Italic numbers in parentheses refer to Literature Cited, p. 254.

[3] MAGNESS, J. R., and BATJER, L. P. Unpublished results.

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among different limbs of a tree as among different trees. Wilcox and Woodbridge (*11*) suggested that the optimum range of boron may be rather narrow and in certain seasons may fall between 10 and 20 p. p. m. and that higher concentrations in the fruit may be injurious. Chittenden and Thomson (*5*) observed injurious effects on Jonathan apples when the boron content of the fruit was increased to 30 p. p. m. On the other hand, Latimer and Percival (*7*) applied as much as 5 pounds of borax per tree to the soil under Golden Delicious and Delicious trees without injury when the fruit from the untreated trees contained as much as 37.4 p. p. m. of boron.

MATERIAL AND METHODS

A commercial grade of borax (sodium borate) or boric acid was applied to the soil under the spread of the branches of apple trees in April, previous to bloom, in the amounts indicated in table 1.

TABLE 1.—*Boron content of apples as influenced by soil applications of borax or boric acid in relation to color and storage disorders*

[Except as noted otherwise, borax applications per tree: 1/3 pound in the spring of 1940, 1/6 pound to the same trees in the spring of 1941, and none thereafter; ground color estimated by comparison with the standard color chart (p. 248)]

Variety, locality where grown, and picking season	Age of trees	Boron content		Ground color		Red color		Breakdown		Scald		Decay	
		Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
Jonathan; Beltsville, Md.:	*Years*	*P. p. m.*	*P. p. m.*	*No.*	*No.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1940	8	12	56	.....	.....	.....	.....	15.6	38.7	0	0	4.5	9.9
1941	9	18	86	2.0	2.4	61	74	.7	33.3	.7	0	1.9	7.6
1942	10	.....	.....	2.7	2.9	77	73	14.5	28.5	0	0	8.3	3.0
Mean	.....	15	71	2.4	2.7	69	74	10.3	33.5	.2	0	4.9	6.8
1944	12	12	20	.....	.....	.....	.....	8.7	16.2	[1] 2.3	[1] 8.7	9.5	11.3
Grimes Golden; Beltsville, Md.: [2]													
1941	9	14	65	1.3	1.5	.....	.....	2.7	6.0	38.4	36.4	.7	.7
1942	10	28	43	1.6	1.8	.....	.....	3.4	1.6	54.8	44.4	.8	0
Mean	.....	21	54	1.5	1.7	.....	.....	3.1	3.8	46.6	40.4	.8	.4
1944	12	.....	22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Grimes Golden; Kearneysville, W. Va.: [3]													
1941	25	13	26 53	1.2	1.2 1.2	.....	.....	0	.5 1.0	59.5	49.5 42.0	1.5	6.0 1.0
1944	28	12	16 28	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Delicious; Beltsville, Md.:													
1940	8	13	46	.....	.....	.....	.....	0	.8	3.0	0	1.9	3.9
1941	9	24	69	1.9	2.2	61	74	.7	.3	31.0	23.0	5.7	1.7
1942	10	18	42	2.9	3.3	77	83	2.0	.7	28.7	18.3	15.3	7.3
Mean	.....	18	52	2.4	2.8	69	79	.9	.6	20.9	13.8	7.6	4.3
1944	12	11	17	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1] Soft scald.
[2] 1/3 pound of borax per tree in 1941 and none thereafter.
[3] 1 or 2 pounds of borax per tree in 1941 and none thereafter. First number in treated columns for each year represents fruit from 1-pound plot and second figure from 2-pound plot.

TABLE 1.—*Boron content of apples as influenced by soil applications of borax or boric acid in relation to color and storage disorders*—Continued

Variety, locality where grown, and picking season	Age of trees	Boron content		Ground color		Red color		Breakdown		Scald		Decay	
		Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
Delicious; Charles Town, W. Va.:[4]	*Years*	*P. p. m.*	*P. p. m.*	*No.*	*No.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1940		14	45					0	1.4	37.8	6.0	0.5	0.9
1944		13	20										
Richared; Beltsville, Md.:													
1941	9	15	46	2.1	2.3	83	87	.3	0	5.7	3.0	.7	.7
1942	10	18	42	2.5	4.0	78	89	2.0	0	14.0	0	9.0	24.0
Mean		17	44	2.3	3.2	81	88	1.2	0	9.9	1.5	4.9	12.4
Rome Beauty; Beltsville, Md.:													
1940	8	12	52					.5	3.6	2.3	2.4	2.3	4.8
1941	9	16	49	1.8	2.1	84	89	3.0	18.5	41.5	12.0	6.5	1.5
1942	10	16	48	2.1	2.0	60	74	5.0	7.3	43.3	36.0	2.3	.7
Mean		15	50	2.0	2.1	72	82	2.8	9.8	29.0	16.8	3.7	2.3
1944	12	10	28										
York Imperial; Beltsville, Md.:													
1940	8	10	42					.9	2.0	6.4	1.0	10.0	5.1
1941	9	11	50	2.7	2.8	73	70	3.2	1.3	21.8	7.8	9.0	7.8
1942	10	16	36	3.1	3.0	73	81	.8	0	17.3	12.0	19.3	16.5
Mean		12	43	2.9	2.9	73	76	1.6	1.1	15.2	6.9	12.8	9.8
Yellow Newtown; Batesville, Va.:[5]													
1941	50+	10	13 19	1.0	1.0 1.0			1.4	.6 .4	2.5	.4 .2	6.9	7.1 7.2
1942	50+	11	19 23	1.2	1.2 1.2			.7	.1 .0	.1	.4 .4	1.7	1.7 1.3
Mean		11	16 21	1.1	1.1 1.1			1.1	.4 .2	1.3	.4 .3	4.3	4.4 4.3
Ben Davis; Charles Town, W. Va.:[6]													
1937	30+	5	29										
1940	33+		21										
1944	37+		14										

[4] 1 pound of borax per tree in 1940.
[5] 1 or 2 pounds of borax per tree applied to certain trees in 1941 and to different trees in another orchard in 1942. First numbers in treated columns for each year and for mean represent apples from 1-pound plots and second number from 2-pound plots.
[6] ¾ pound of boric acid per tree in 1937.

To determine the storage quality of the apples bushel lots from replicate trees were placed in storage at harvest and held at 31° to 32° F. until the latter part of their normal storage period when they were post-ripened for a week at 70°, examined for storage disorders, and sampled for chemical analysis. In 1940 one picking of well-matured fruit was made for each variety. In 1941 and 1942 several pickings of most of the varieties were made at different maturities. In 1944 samples were taken from the different plots for boron determination to find out to what extent the effect of the earlier applications of boron was reflected in the composition of the fruit. With the exception of Jonathan none of the 1944 fruit was held in storage.

In some instances the apples that dropped during the harvest period were counted. At harvest the firmness of the flesh was determined by means of a standard apple pressure tester. The percentage of the fruit surface with red color was estimated, and the shade of green, or ground color, was found by comparison with a standard color chart on which the colors grade from a green (No. 1) corresponding to 20 K 6 in Maertz and Paul's dictionary of color (*8*) to a greenish yellow (No. 4) corresponding to 10 I 1.

Samples of 20 apples from the stored lots were used for the chemical analyses. Boron was determined on the ashed tissue by Wilcox's electrometric-titration method (*12*). From other samples the juice was expressed through canvas by means of a hydraulic press at a pressure of 8,000 pounds over an area of about 16 square inches. The expressed juice was used for the determination of soluble solids by means of an Abbé refractometer, pH value by means of a Beckman pH meter with a glass electrode and a saturated calomel half cell, and titratable acidity by titration with N/20 sodium hydroxide to a pH of 7.0 by the use of the Beckman pH meter.

EFFECTS OF TREATMENTS ON FRUIT

BORON CONTENT

The boron content of the apples from the untreated plots ranged from 5 to 28 p. p. m. (table 1). Except for that of Ben Davis, boron was in the range of sufficiency as indicated by other investigators (*1*, *5*), and only the fruit of Ben Davis was affected with internal cork. Consequently, the borax applications tended to change the boron status of the fruit from sufficiency to an excess.

The application of one-third of a pound of borax per tree in 1940 to 8-year-old trees of the Jonathan, Delicious (including Richared), Rome Beauty, and York Imperial varieties at Beltsville resulted in a boron content of the fruit of 42 to 56 p. p. m. in 1940 when fruit from the untreated trees contained only 10 to 13 p. p. m. (table 1). A similar application of borax to Grimes Golden in 1941 resulted in a corresponding increase in the boron content. In 1941 an additional one-sixth of a pound of borax was applied to each of the trees that received one-third of a pound in 1940. The boron content of the fruit ranged from 46 to 86 p. p. m., being highest in the Jonathan. The use of one-sixth of a pound of borax per tree maintained and possibly increased the boron status of the trees. Although no boron was applied to these plots in 1942, there was very little decrease in the boron content of the fruit. By 1944, 3 years after the last borax application, the boron content was considerably reduced but was still much higher than that of the untreated. The application of 2 pounds of borax per tree to 25-year-old Grimes Golden trees at Kearneysville, W. Va., resulted in a boron content of the fruit about equivalent to that obtained with one-third pound of borax at Beltsville and double that obtained with 1 pound at Kearneysville.

Two-thirds of a pound of boric acid was applied to the soil under Ben Davis trees more than 30 years old and growing on a boron-deficient soil near Charles Town, W. Va. The untreated fruit had a boron content of only 5 p. p. m. and developed over 80 percent of

internal cork. The boric acid application increased the boron content of the fruit about fivefold. Seven years after this application the fruit from the treated trees still showed nearly three times as much boron as the fruit at the start of the experiment. No storage tests were conducted with this fruit.

Near Batesville, Va., 1 or 2 pounds of borax per tree was applied to the soil under very large Yellow Newtown trees (more than 50 years old); the applications were made to different trees in the two seasons. Although the 2-pound applications about doubled the boron content of the fruit, they brought the boron to only 19 and 23 p. p. m. Similar increases in boron content of fruit following borax applications to the soil have been reported by Chittenden and Thomson (*4*, *5*), Wilcox and Woodbridge (*11*), and Latimer and Percival (*7*).

PHYSICAL AND CHEMICAL CHARACTERISTICS

The borax applications had no appreciable effect on the soluble solids or on the active or the titratable acidity of the fruit. Neither did they have any apparent effect on the dessert quality of the fruit. In general, no consistent effect of the borax on firmness of the fruit either at harvest or after storage was noticed. When ripened at 70° F. immediately after harvest, however, Jonathan and Grimes Golden apples from the borax-treated plots seemed to ripen and soften more rapidly than those from the untreated plots. In 1941 the Jonathan apples from the treated plots that showed break-down after storage tested firmer (15.2 pounds) than the sound fruit (12.4 pounds) and the sound fruit from the treated plots was firmer than that from the untreated plots. Except for the 1941 results for Jonathan, these results agree in general with those of Wilcox and Woodbridge (*11*), who found no apparent effect of boron treatments on the firmness of Jonathan and McIntosh apples either at picking time or later.

The application of borax considerably hastened dropping of Jonathan and Grimes Golden apples. In 1941 and 1943 an average of 16 percent of the Jonathan apples dropped from the untreated trees and 31 percent from the treated trees; the respective percentages for the Grimes Golden variety were 7 and 15.

Apples from the borax-treated plots appeared to be somewhat more yellow as shown by the values in table 1. The increased yellowing was particularly true of Grimes Golden when ripened immediately at 70° F.[4] The finding is in general agreement with the results of Latimer and Percival (*7*), who noted yellowing of the fruit on the tree with heavy applications of borax. On the other hand, Bryden (*3*) observed that under conditions of boron deficiency a soil application of 1 pound of borax per tree caused the fruit to retain a deep-green color for a longer period of storage. Under similar conditions Phillips and Johnston (*9*) also observed that before harvest, apples in treated plots were somewhat greener than those in boron-deficient plots. Thus, where boron was deficient and internal cork was developing, ground-color changes were advanced. When just enough borax was added to correct the deficiency, ground-color changes were retarded, but when excess borax was added, the ground-color changes

[4] Data not presented.

were again advanced. In this respect a deficiency or excess of boron may have similar effects.

There are also indications, from the data in table 1, that a higher percentage of the fruit surfaces of the apples from the borax-treated plots than of those from the untreated plots developed red color, but the observations were not entirely consistent. Differences in red color may have been reduced by greater dropping of the more highly colored fruit from the treated plots.

STORAGE DISORDERS

The relation of soil applications of borax to the development of storage disorders is also shown in table 1. Although there were instances in which there was considerable difference in decay in apples from the treated and the untreated plots, the differences were not consistently in favor of either. The results for Jonathan, in table 1, indicate increased decay with borax treatment in two seasons but a reduction in 1942 and no significant difference in 1944. Chittenden and Thomson (*4*, *5*) found a marked increase in decay in Jonathan apples as the boron content increased.

Severe break-down occurred primarily in fruit of the Jonathan variety. Both 1940 and 1942 were light crop years and considerable break-down occurred in the untreated Jonathan apples, but it was very much more severe in the fruit from the treated plots. In 1941 four pickings of Jonathan were made; in no case was there appreciable break-down in the untreated fruit, but in that from the treated plots break-down was very severe and occurred even in the first picking, when the fruit was poorly colored and immature from the standpoint of flavor as well as color. Thus, this break-down, or browning, of the flesh appears to be a type of boron injury and not the usual storage break-down of the fruit associated with overmaturity and overripeness. The break-down was further distinguished from the usual old-age break-down in that the apples with break-down in the treated lots were not mealy and soft but springy and firm, and, as pointed out on page 249, they had a higher pressure test than the sound apples. Apples with borax injury frequently showed no external evidence of the break-down until it became very severe. Typical examples of the borax-injury type of break-down shown in figure 1 illustrate the general browning of the flesh that occurs under these conditions. Boron determinations were made on the fruit showing break-down. The boron content of such fruit was found to be somewhat higher than that of sound fruit from the treated plots. However, boron content was not the only factor involved, as some of the sound lots showed higher boron content than some lots with break-down. By 1944 the boron content of the fruit was down to 20 p. p. m., and although the apples from the treated plots still developed more break-down than those from untreated plots, the difference was not statistically significant and the break-down was the typical old-age kind. The results for Jonathan are in agreement with those of Chittenden and Thomson (*4*, *5*) and of Wilcox and Woodbridge (*11*).

Rome Beauty was the only other variety to show appreciable break-down, the most severe occurring in 1941. As with Jonathan,

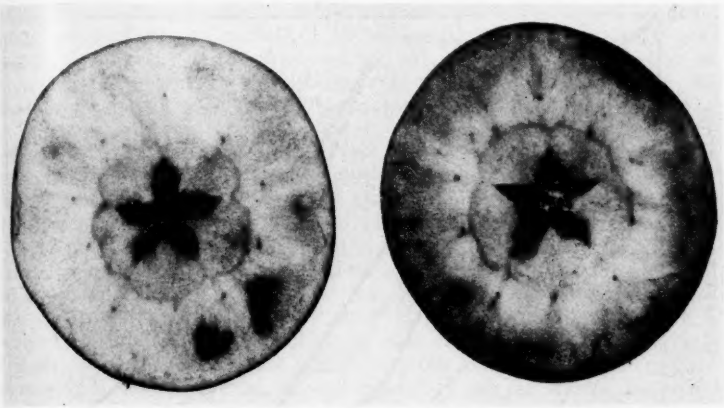

FIGURE 1.—Jonathan apples from borax-treated plots of the 1940 crop showing internal browning and break-down caused by boron. Photograph taken in January 1941, after storage at 31° to 32° F. and post-ripening for 1 week at 70°.

the break-down was worse in the apples from the treated plots. There was no appreciable break-down in either the untreated or the treated fruit of the other varieties. Boron has been found to increase flesh browning of McIntosh apples (*11*).

Although the apples were packed with shredded oiled paper, considerable scald developed in lots of all varieties except Jonathan and Yellow Newtown. In all instances where at least 5 percent of the untreated apples developed scald, fewer of the fruits from the borax-treated plots than of those from the untreated plots scalded (table 1).[5] The values generally are averages for several pickings at different maturities. In the early pickings of immature apples nearly 100 percent of them frequently scalded regardless of boron treatment. On the other hand, with late pickings, when the apples were well-matured, there was no scald on either the untreated or the treated lots. In intermediate pickings in which partial control of scald was obtained the greatest reduction in scald from the borax applications was apparent. Averaging all pickings tended to mask or reduce the differences observed at the critical intermediate maturities. In general, apples could be picked from 3 to 5 days earlier from the treated plots than from the untreated ones without appreciable development of storage scald. Examples of the relation of borax treatments to storage scald at different picking maturities are shown in figure 2 for Grimes Golden and Rome Beauty for 1942 and for York

[5] In 1945 additional results were obtained with York Imperial and Stayman Winesap apples grown on two soil types near Arendtsville, Pa. Scald was reduced from 67 percent on fruit from untreated York Imperial trees to 46 and 39 percent, respectively, on fruit from trees treated with ¾ and 1½ pounds of borax per tree; and from 82 percent on fruit from untreated Stayman Winesap trees to 70 and 56 percent, respectively, on fruit from trees treated with ¾ and 1½ pounds of borax.

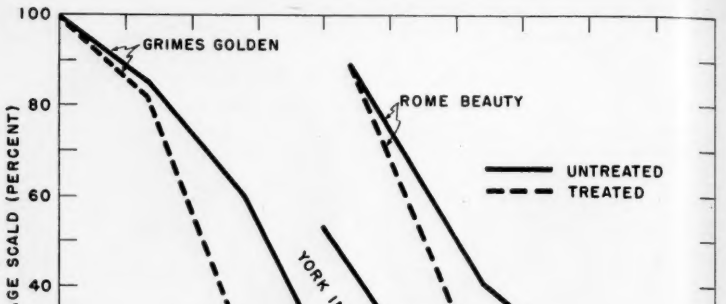

FIGURE 2.—Development of scald on apples after storage and post-ripening in relation to borax treatments and picking maturities.

Imperial for 1941. Analyses of scalded and scald-free apples from the same lots showed the scald-free ones to be higher in boron content. No previous report has been found relative to the effect of borax applications on storage scald.

DISCUSSION

In the first season the borax treatments hastened dropping and development of both red and ground color and increased break-down of Jonathan apples; also they reduced scald in other varieties. Since all of these factors are associated with advanced maturity, or are indications of it, it was stated in a preliminary report (*2*) that the borax treatment had advanced maturity. On the basis of the additional results obtained it seems doubtful whether maturity was advanced. Certainly from the standpoint of flavor the apples could not be picked any earlier from the treated plots than from the untreated ones. Although earlier dropping in the treated plots might necessitate earlier picking, it would not necessarily indicate advanced maturity. The break-down that occurred in Jonathan apples was not associated with maturity, because it was as severe in very early pickings of distinctly immature apples as in later ones. The break-down in the Jonathan was somewhat different from that due to old age and is now considered to be a direct boron injury. On the other hand, with a variety such as Grimes Golden in which picking maturity depends largely on its susceptibility to scald, picking might be advanced by the application of borax to the soil. Other investigators (*6*, *9*), working with McIntosh under boron-deficiency conditions,

have observed an apparent delay in maturity with boron applications, particularly as indicated by retardation of dropping (*6*) and delay in yellowing of the ground color (*9*). Thus, the application of borax under deficiency conditions may have an effect opposite to that produced by applications to trees that are not deficient.

Varieties apparently differ greatly in their susceptibility to boron injury. Jonathan, for example, has been found in these and other investigations to be extremely subject to injury. In this variety internal break-down is likely to be very serious if the boron content of the fruit becomes greater than 30 to 40 p. p. m. Therefore, boron should not be used on Jonathan unless the soil is definitely known to be deficient. Under such conditions extreme care must be exercised to avoid an excess. Other investigators (*9, 11*) have indicated that the McIntosh may be rather susceptible to boron injury. There is some indication that Rome Beauty also may be subject to injury. On the other hand, certain varieties, such as Grimes Golden, Delicious, and York Imperial, have been benefited (as shown by scald reduction) by the same applications that have caused serious injury to Jonathan; however, this beneficial effect might be counterbalanced by earlier dropping of the fruit unless harvest sprays are used to retard dropping. Latimer and Percival (*7*) indicated that Golden Delicious and Delicious can tolerate relatively heavy applications of borax (as much as 5 pounds per tree). Until more is known relative to the effect of boron on these and other varieties considerable caution should be used in the application of this material.

Determinations of boron in the fruit in 1944, 3 to 4 years after the borax was applied, still showed some effect of the application in the boron content of the fruit but much less than in the season of application. In the case of Ben Davis, more than 30 years old, a single application of two-thirds of a pound of boric acid per tree in a boron-deficient soil was still effective after 7 years. Thus, a single application of borax or boric acid may be depended on to give protection for several seasons. However, the period of effectiveness would vary with such factors as the size of the application, the age of the trees, the deficiency in the soil, and the type of soil. Analysis of the fruit would be the only dependable means of determining the need of further applications before deficiency symptoms occur.

These results indicate that, even where boron is apparently sufficient to prevent the formation of internal cork, a reduction in storage scald may be obtained with some varieties by soil applications of borax. Under such conditions applications of borax may be desirable to improve the keeping quality of the fruit. Powers (*10*) stated that under Oregon conditions boron seemed to do this, but he presented no evidence to indicate how the improvement was accomplished.

SUMMARY

From 1940 to 1944 experiments were conducted on several varieties of apples in various localities to determine the effects of treatment of the soil with borax upon the boron content of the fruit and its relation to storage quality. With one exception there was sufficient boron in the soils to prevent the development of internal cork in the fruit.

The boron content of the fruit was greatly increased by the borax applications, frequently to more than 40 p. p. m., a quantity greatly in excess of that necessary to control internal cork. The boron content of the fruit decreased gradually from year to year after the initial borax application when no further borax was applied but was maintained considerably above that in the untreated fruit for 3 and 4 years.

The borax applications had no appreciable effect on the soluble solids and acidity of the fruit and no consistent effect on their firmness. Sometimes they caused earlier dropping of the fruit. Under some circumstances they hastened the ground-color changes from green to yellow and the development of red. Dropping and color changes are associated with advanced maturity. As changes in dessert quality were not hastened by the treatments, earlier picking could not be practiced without sacrificing dessert quality.

The relation of boron content and decay was not consistent.

Applications of borax influenced the development of certain physiological disorders during storage. An internal break-down in Jonathan apples was greatly increased by the treatments; a similar break-down in Rome Beauty was increased during one season. On the other hand, storage scald of Grimes Golden, Delicious, Rome Beauty, and York Imperial was appreciably reduced by the treatments.

The results indicate that where borax applications to the soil resulted in a boron content of the fruit in excess of that necessary to control internal cork they have considerably influenced the physiology of the fruit and may be beneficial or detrimental to the storage quality of the fruit, depending on variety, concentration, and probably other factors.

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